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ABSTRACT

This publication is an administrative guide or manual for energy conservation at higher education facilities. Text and diagrams describe a broad range of energy conservation equipment and management options. Chapter titles, which indicate contents, are: (1) Energy Overview; (2) Energy: Its Conversion, Use, and Waste; (3) Energy Data Base; (4) Evolutionary Approach to Energy Conservation; (5) Purchased Utilities; (6) Finance and Investment; and (7) Energy Management and Organization Incentives. A glossary is included. (MR)

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Energy Management for Colleges & Universities

ACE
APPA
NACUBO
ENERGY
TASK FORCE

SE 026 794

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Preface

This book is based on a manual developed by the Energy Task Force for use in a series of energy management workshops conducted by the task force under a cost-sharing contract with the Federal Energy Administration. These workshops, held in nine cities from August through November 1976, were designed for the physical plant directors and the chief business officers of colleges and universities. The workshops sought to provide these administrators with the opportunity to become more aware of the problems and benefits in developing and implementing effective energy management programs and to learn cost-effective energy management techniques.

The Energy Task Force is a joint activity of the American Council on Education (ACE), the National Association of College and University Business Officers (NACUBO), and the Association of Physical Plant Administrators of Universities and Colleges (APPA). Its major source of financial support has been a generous grant from the Exxon Corporation. The group was formed to create programs designed to stimulate, improve, and insure the efficient use of energy by colleges and universities and to keep administrators of nonprofit institutions of higher education aware of emerging national energy policy. Members of the task force are selected from a geographically and institutionally diverse group of colleges and universities in order to reflect more accurately the broad range of energy concerns in higher education. Members of the task force at the time the workshop manual was prepared were:

John F. Embersits, *Chairman*, Energy Advisor to the Yale Corporation, Yale University
Ralph S. Kristoferson, Director, Facilities Planning and Construction, The University of Texas System
Elmo R. Morgan, Director of Facilities, University of California, Berkeley
H. Stanley Palmer, Plant Engineer, Colby College
Gae P. Russo, Director of Facilities Planning and Operations, Kent State University
Theodore B. Simon, Assistant Vice President for Physical Plant, Michigan State University

Development of the workshop curriculum required the collective knowledge of chief business officers and physical plant directors from a variety of institutions. Accordingly, the Energy Task Force formed a Program Development Committee comprised of four business officers and five physical plant directors, who were charged with devising the structure and content of the workshops. Members of this committee included:

John P. Moran, *Chairman*, Vice President for Facilities, Princeton University
Harold J. Anderson, Assistant Director-Physical Plant, Brigham Young University
George Berry, Director of Physical Plant, University of Wisconsin-Milwaukee
Bernard Carpenter, Vice President for Business Affairs, Bates College
William R. Dickson, Director of Physical Plant, Massachusetts Institute of Technology
Jason Mavis, Director, Physical Plant Services, Stanford University
John C. Robertson, Administrative Vice President, Junior College District of St. Louis
Dallas Sullivan, Director of Energy Conservation, Physical Facilities Services, The Ohio State University
H. S. Thomson, Director, Facilities Planning and Construction, University of Washington

Based on the recommendations of this committee, the Energy Task Force developed an instructor's text, a participant's manual, and audiovisual aids for use in the series of nine

workshops. The task force is indebted to the members of this committee as well as to many other persons from within higher education for their participation in and support of this and other task force projects. The Energy Task Force also appreciates the assistance provided by Enviro-Management & Research, by Exxon Marketing Technical Services, by the National Electrical Manufacturers Association, and by the National Electrical Contractors Association.

The workshop faculty included Messrs. Berry, Dickson, Moran, Sullivan, and Thomson, as well as the following:

Daniel J. Altobello, Vice President for Administrative Services, Georgetown University
William L. Campbell, Director of Plant Planning and Operations, The Johns Hopkins University
Robert H. Fuller, Research Associate, Department of Mechanical Engineering, The Ohio State University
Carl Hagge, Environmental Engineer, Massachusetts Institute of Technology
Dale L. Hawn, Director of Physical Plant, Grinnell College
Jerold W. Jones, Associate Professor, Architectural Engineering, The University of Texas at Austin
Woodrow R. Macke, Vice President for Business Affairs, Otterbein College
Lawrence F. O'Neill, Coordinator of Physical Facilities, St. Louis City-County Junior College
Donald S. Parry, Associate Director of Physical Plant, University of Maryland
Gerald Scott, Plant Engineer, Texas A&M University
James Sneathen, Assistant Director of Energy Conservation, Michigan State University

Many of the faculty members reviewed portions of the manuscript of this book.

Energy Task Force Program

The workshop series was one project within the overall energy management program developed by the Energy Task Force, which consists of three basic components: energy information sharing, institutional energy management, and federal focus.

Energy Information Sharing

In the belief that a free exchange of energy conservation information is an essential element in any effective energy management program, the Energy Task Force is accumulating and disseminating relevant data and materials. The sharing of institutional advances in energy conservation, as well as problems encountered and solutions developed, is beneficial to all of higher education. Such information sharing will lead to an energy awareness that will be of significant value in addressing short-term energy problems and rapid technological advances. Task force efforts in the energy information-sharing project include (1) data gathering and analysis and (2) publications.

Data Gathering and Analysis. In order to represent the energy concerns and conservation efforts of higher education and to propose programs for assistance, a reliable data base must be established. Accordingly, the task force has completed one brief survey of energy cost and consumption trends in higher education as well as a second, more comprehensive data-gathering effort.

Publications. The task force disseminates information related to the energy concerns of higher education in order to keep colleges and universities informed of energy management developments. Copies of publications are mailed to ACE, APPA, and NACUBO representatives, and additional copies are available from the offices of NACUBO and APPA.

Institutional Energy Management

In order to stimulate energy management improvements and to assist institutions of higher education in their efforts to implement and sustain energy consumption and cost reduction programs, the Energy Task Force has embarked on a series of projects designed to provide colleges and universities with practical energy management tools. Projects include an energy audit and energy education.

Energy Audit. A successful institutional energy management program depends on up-to-date energy cost and consumption data, as well as on an understanding of energy use within the variety of buildings on a campus. An energy audit has been conducted by the task force in order to gather and disseminate the type of technical information that will encourage and allow an institution to compare its energy performance with that of similar institutions. The task force collected energy cost and consumption data from institutions that were metering energy used in specific facilities so that a pro-

file of energy use and cost could be derived on a per-square-foot basis for a variety of types of campus facilities. Copies of the results of the audit were mailed to ACE, APPA, and NACUBO member institutions in May 1977.

Energy Education. The ability of the chief business officer and the physical plant director to work together effectively is critical for the success of any energy management program. Each administrator must be sensitive to the needs, problems, and opportunities the other faces when implementing and managing a conservation effort. Recognizing this requirement, as well as the need for more information on successful energy management techniques, the task force developed the workshop series mentioned earlier. It was hoped that by bringing the chief business officer and physical plant director together to focus on effective energy management methods, implementation and improvement of energy management programs throughout higher education would result. In addition to these workshops, the task force has held and will continue to hold workshops and seminars on such topics as central computer control systems and the use of computers for analyzing building efficiency.

Federal Focus

While the Energy Task Force works on the development and implementation of programs designed to assist colleges and universities in their efforts to effectively manage energy resources, it must also pay close attention to energy policy formulation in Washington, D.C. In order to remain informed on energy issues and to gain an energy identity for higher education, the task force meets regularly with officials of the FEA and provides data to Congressional staff members in an effort to insure the recognition of higher education as a unique energy-consuming sector of the economy. In addition, the task force maintains a close working relationship with the Energy Research and Development Administration (ERDA), the Department of Housing and Urban Development (HUD), and the Department of Health, Education, and Welfare (HEW) so that these agencies may benefit from the experience of the task force and so that higher education will be informed as national policy emerges.

Relations with Institutions

The programs of the Energy Task Force do not pretend to provide complete solutions to complex energy problems. Rather, the task force attempts to promote a wider sphere of energy awareness so that colleges and universities, already burdened with increasing costs in nearly every area, will be better positioned to manage their resources effectively.

As with any small group addressing difficult problems, the Energy Task Force relies heavily on the experience and responses of the institutions it serves. The common energy concerns of higher education, as well as the unique and effective communication channels inherent in the college and university system, make participation between the task force and the institutions it represents extremely important. Regional differences in energy supplies and costs, and the variety of state codes and environmental restrictions under which colleges and universities must operate, mean that effective development and implementation of programs by the task force will depend on information fed back from the field.

The energy issues will not fade away. The need to reorder consumption practices and priorities is urgent. As a traditional solution-seeking sector of the nation, higher education must not only work on developing ideas to assist others, but also, even more importantly, must implement programs that will allow colleges and universities to help themselves. The quality of academic service offered by institutions of higher education, as well as the national goal of energy independence and economic stabilization, demands nothing less.

Acknowledgments

The Energy Task Force hereby conveys its special appreciation for the generous funding of its overall program by the Exxon Corporation, which has made possible the many accomplishments of the task force. Early recognition by the Exxon Corporation of the need to support energy management efforts in higher education encouraged the establishment of the task force, and Exxon's continuing support has been a major factor in the high level of accomplishment achieved.

The task force also appreciates the general support of its activities by the International Business Machines Corporation.

The Federal Energy Administration is commended for its prompt and positive financial support of the energy management workshop program through a cost-sharing contract with the task force. These workshops have made an important contribution to the ability of higher education to reduce its rate of energy use.

The task force also expresses its appreciation to the Center for Strategic and International Studies of Georgetown University and to the Center's director of the Office of National Energy Problems, Francis X. Murray, for permission to use certain flow charts and related text from the book *Energy: A National Issue*. These charts appear as figures 1.3 through 1.8 in this book.

Introduction

Higher education must concern itself with the economics of the energy problem. However, it has several unique features that complicate its ability to react with a single voice to the energy policies and economics that have emerged since 1974. Colleges and universities are simultaneously *diverse, decentralized,* and *transient* in their energy uses, possessing limited cost pass-through opportunities. While these features exist in other sectors of the economy, it is their *simultaneous* presence that produces a special problem for higher education.

Diversity

Higher education is a spectrum of widely differing institutions. In most, the educational mission is accomplished in classrooms, libraries, dormitories, and dining halls. As one moves farther across the spectrum of complexity, teaching laboratories, research institutes, museums, galleries, and medical centers join the traditional campus stereotypes. The result is a montage of building diversity and energy consumption variations that defies any attempt at simple generalization. On a single campus, the diversity of building design, engineering, age, function, and, therefore, energy costs mandates a highly individualized diagnostic and prescriptive approach to minimizing energy waste.

To further compound these characteristics of college and university physical plants, decades of inexpensive energy have been reflected in engineering design. To minimize the capital cost of new construction, colleges and universities have locked themselves into patterns of predesigned energy waste. It is obvious that buildings so designed will not lend themselves to consumption reductions merely because the price of energy increases; conservation programs must be focused on the technological causes of energy waste.

The technical expertise to cope with the conservation challenge is often not available at many institutions. What is routine and sound conservation management at a large, well-staffed university is often well beyond the capabilities of the small college. Many of the latter are not only financially less able to bear the premium costs of energy waste, but are also unable to technically help themselves reduce such costs.

In summary, the diversity of energy consumption, energy costs, geography, and technical expertise complicates the conservation action required to attack higher education's energy waste.

Decentralization

Higher education does not fit the model of an authoritative, centralized, institutional structure. The essence of the educational mission, that is, the pursuit and transmission of knowledge, must be a highly decentralized process. Consequently, the structure—organizational, managerial, and physical—of the university tends to be decentralized about the focal points of learning. The autonomous leadership of deans, directors, and department chairmen, as well as the pursuit of knowledge by the individual researcher, provides a pattern of energy consumption that is highly decentralized at best, and in some cases of practical politics, even personalized.

Billions may have been spent in constructing central energy plants for steam, electricity, and chilled water, but it is the demand from users that will ultimately determine the consumption pattern of the institution.

Transient Populations

Students come and go; faculty, researchers, deans, department chairmen, presidents, business officers, and other administrators change. The transient nature of campus populations presents an ongoing and slightly more difficult problem in management than does a more tightly structured, less transient organization.

Limited Cost Pass-Through Capabilities

In highly inflationary situations it is essential for every business organization to reduce controllable costs, but when the costs of business increase beyond the organization's absorptive capacity, prices for the product must increase. The 1974 escalation in crude oil prices started a wave of general commodity price increases with surprising speed. No institutional budget escaped; many colleges and universities witnessed their utility bills tripling in very short time and without much warning. In 1977 the ripples of these increases were still being felt in regions of the country that escaped the initial increase in 1974.

While oil companies, utilities, airlines, petrochemical, and other industries quickly passed cost increases along to consumers, the institutional community, by and large, could not. Locked into budget cycles and allocation plans spanning a 12- to 18-month period, neither abrupt tuition hikes nor instantaneous staff reductions were options readily available. Unlike regulated industries and many businesses, colleges and universities are limited in their flexibility to pass on costs to their "customers."

These are the factors that render higher education's energy management problems as unique. In no other sector of the economy do all of the above operate simultaneously. Therefore, recognition of these difficulties and the consequent tailoring of conservation programs to adapt to them will increase the probability for program success.

Energy Overview

The United States, with about 6% of the world's population, consumes about 35% of the planet's energy output. On a per capita basis, persons in the U.S. use as much energy in just a few days as half the world's population consumes in a year. The U.S. has been developed without any significant restrictions that are due to a lack of energy or mineral resources.

There has, however, been a fundamental change in the energy position during the 1970s, during which the country switched from an energy surplus to an energy deficit. Growing dependence on oil indicates that this deficit state is not likely to change for decades, if ever.

The purpose of this chapter is to examine briefly the supply and demand of energy and to review the availability, use, and price of energy in the U.S. to enable the reader to gain a better understanding of why the country is so dependent on oil and what the alternatives are for the future.

International Use of Fuels

Various forms of energy have been available for use during the 20th century, and the changes in the use of these forms of energy are illustrated in figures 1.1 and 1.2. In order to put all fuels on a common basis, an energy unit of one million barrels per day of oil equivalent (MB/DOE) is used. In part, MB/DOE was chosen as the unit because a barrel is easier to visualize than a kilowatt-hour or a Btu. This standard unit also provides a common denominator, which permits a comparison of the relative importance of various fuels. Finally, oil is one of the key U.S. fuels, and imported oil is the major factor in the international oil dilemma.

The conversions of oil equivalency are accomplished by calculating the energy that would be produced from the various energy forms and then converting that energy into the number of barrels of crude oil that would have been used in order to obtain the same amount of energy. For instance, the tons of coal burned for a particular use have been taken and converted into the equivalent barrels of oil that would have been burned in order to obtain the same amount of heat.

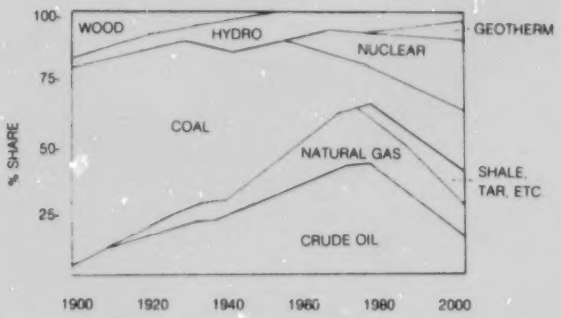

Figure 1.1. Changes in Energy Use

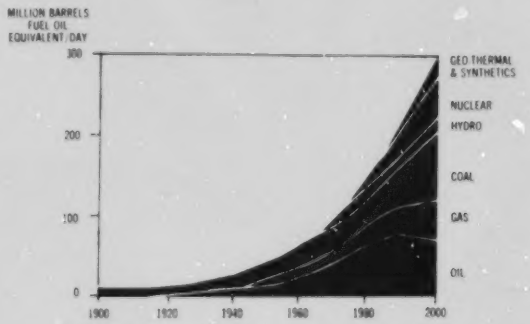

Figure 1.2. World Energy Consumption Growth

It is evident from figure 1.2 that in 1970 the world was using the oil equivalent of 100 million barrels per day, and if a 3.5% growth rate were to continue until the year 2000, the world would then be using approximately 280 MB/

DOE. The present U.S. share of world consumption is about 35 MB/DOE, or about one-third of the world's consumption. Similarly, western Europe is consuming about 25 MB/DOE, Japan, 8, and the Communist bloc, about 18, leaving approximately 15 for the rest of the world.

The United States Energy Situation: 1960–1990

Figures 1.3 to 1.7 reveal what has happened to the U.S. energy situation during the last several years and what may happen in the next several years. Each figure is divided into four areas to show the flow of energy into and through the U.S. energy system.

Supply/Demand. The left side of each figure shows the type and amount (supply and demand) of energy put into the system, measured in millions of barrels of oil per day equivalency units.

Form of Use. The form-of-use portion of the figure identifies the conversion of energy from one form to another, such as in the case of electricity.

End Uses. This section of the figure identifies the energy-using sectors by the type of energy required in each. Four sectors are represented: residential/commercial, industrial, transportation, and non-energy (energy used in the production of petrochemicals, fertilizers, etc.). Colleges and universities are classified in the residential/commercial sector.

Efficiency. This portion of the figure shows how efficiently, or inefficiently, energy is used. Each figure is drawn to the same scale so that dimensional changes represent the actual growth patterns in the country during the period covered.

Oil—1960

As can be seen in figure 1.3, the total U.S. oil supply (9.7 million barrels per day) in 1960 consisted of oil from domestic sources (7.8 MB/D) and oil from imports (1.9). A small amount of oil (0.3) was used in the generation of electrical energy. The U.S. exported some oil (0.2) in the form of petroleum products; utilized a considerable amount (2.0) in residential and commercial end use (about 75% single dwelling and the remainder apartment houses, offices, shopping centers, etc.); considerably less (1.3) in industry (iron and steel, auto manufacturing, etc.); even less (0.8) in non-energy use (manufacture of fertilizers, plastics, paints, etc.); and used the largest share of oil (5.0) in transportation (autos, planes, trains, etc.).

Coal—1960

In 1960, total domestic coal production was less (in heat equivalent) than that of oil or gas. Coal production was equivalent to about 5.3 million barrels of oil per day. A large amount of coal (2.0 MB/DOE) was used to generate electricity—in fact, more than half the country's electrical energy in 1960 was generated by burning coal. A relatively small amount (0.5) was exported, primarily for metallurgical purposes, to Europe and Japan. About the same amount (0.5) was used, primarily for heating purposes, in the residential/commercial end use, and only a trace (0.1) was used in transportation. (There were some coal-fired railroads operating in 1960, mostly in the West and in freight service.) The largest single use of coal (2.3) was in industry—iron and steel production, etc. A small amount (0.1) was used in the non-energy sector.

Gas—1960

The country's gas supply (5.9 MB/DOE) was primarily from domestic sources (5.8), and only a trace (0.1) was due to imports. Some gas (0.8) was already being burned under boilers to produce electrical energy. A considerable quantity (2.0) was utilized in residential and commercial end use, and the largest single use (2.8) went to industry. In 1960, industry already received more energy from gas (2.8) than from coal (2.3). Some gas (0.2) was used in the non-energy sector, and an equally small amount (0.2) was used in the transportation sector, primarily as energy to operate pipelines.

Hydroelectric Energy—1960

A small portion of U.S. energy production was due to hydroelectric power (0.3 MB/DOE) in 1960. There was no significant production of energy from nuclear, geothermal, or other energy sources in that year.

Form of Use—1960

In 1960, the only significant conversion of one type of energy into another was for electric energy generation. The total unit input (3.4 MB/DOE) to electric energy generation that year consisted of oil (0.3), coal (2.0), gas (0.8), and hydroelectric energy (0.3). Almost

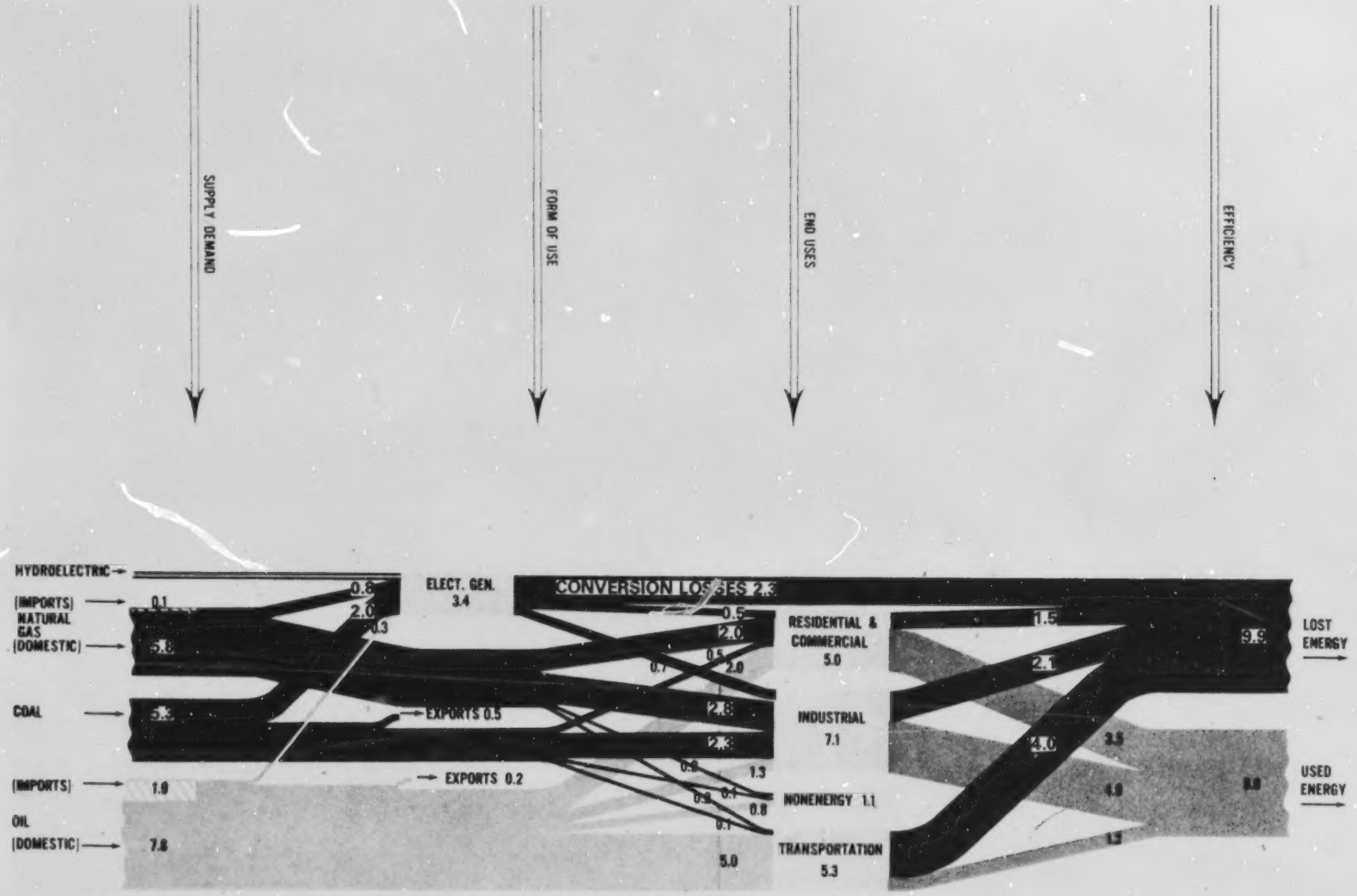

Figure 1.3. Energy Flow—1960

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two-thirds (2.3 MB/DOE) of the total input to the electric generation system was lost in the conversion process from heat to electricity; this loss is shown on the chart as *conversion losses*, which are not unusual. For example, the maximum conversion efficiency in conventional steam electric plants is about 40%.

About half of the actual electricity generated was transmitted to residential and commercial (0.5 MB/DOE) end use, and slightly more (0.7) was utilized by industry. In 1960 it was not even possible to draw a flow line indicating use of electricity by the transportation sector; the East Coast electrified railroad grid and the various electrically driven mass transportation systems did not utilize enough electricity during 1960 to be represented on this flow pattern.

End Uses and Efficiency—1960

In examining the efficiency with which each end use sector converts its supply of total energy to useful work, it can be seen that the least efficient user was transportation. This sector, with an input of 5.3 MB/DOE (about 95% from oil), lost or rejected over 75% (4.0 MB/DOE) of the total heat energy supplied to it. Accordingly, only about 25% (1.2 MB/DOE) was actually converted to useful work moving autos, trucks, trains, aircraft, and ships. This alarmingly low efficiency is primarily the penalty paid for the methods used to obtain mobility.

The industrial sector, in utilizing its total input of 7.1 MB/DOE, lost about 30% (2.1 MB/DOE), while effectively utilizing about 70% (4.9 MB/DOE).

The residential/commercial sector took its total input of 5.0 MB/DOE (of which 80% of the demand was met by natural gas and oil), losing about 30% (1.5 MB/DOE) and utilizing nearly 70% (3.5 MB/DOE).

Finally, in examining the overall efficiency of the system in 1960, it can be noted that the total losses, or lost energy, were composed of the conversion losses (2.3 MB/DOE) from electrical generation and the losses from the residential and commercial (1.5), industrial (2.1), and transportation (4.0) sectors for a total of 9.9 rejected during the year. The useful energy was made up of that actually utilized in residential and commercial (3.5), industrial (4.9), and transportation (1.2), for a total of 9.6 MB/DOE of energy. In 1960 there was thus a loss of about 51% and a utilization of slightly over 49% of the total fuel energy consumed.

Energy Flow—1970

Figure 1.4 shows U.S. energy flow in 1970; it is on the same scale as the figure for 1960.

The decade between 1960 and 1970 will probably be noted for two reasons: first, it was the decade of a massive expansion in the use of natural gas, and second, it was the early stage of the "take-off" in the move toward greater use of electricity. While oil use increased slightly less than 50% (from 9.7 to 13.9 MB/DOE) and coal increased slightly over 40% (from 5.3 to 7.4), the use of natural gas almost doubled (from 5.9 to 10.7).

Flow lines representing nuclear (0.1 MB/DOE) and geothermal (0.003) energy are seen for the first time in the 1970 figure.

Electrical energy more than doubled (from 3.4 MB/DOE to 7.1) in the decade between 1960 and 1970. For the first time an electric use line is shown (0.007), flowing from the electrical energy generation section to that of transportation.

Other things to note are the disappearance of coal use in the transportation sector, the major decrease of coal in residential and commercial end use (down to 0.2 MB/DOE in 1970 from 0.5 in 1960), and that a significant amount of natural gas (0.3) and coal (0.1) was being used in the manufacture of non-energy products (mostly for fertilizer and plastics). Oil imports amounted to about 25% of U.S. oil use.

Lost energy (14.7 MB/DOE) was slightly less than used energy (15.0). The efficiency of national overall energy conversion for the year 1970–1971 may turn out to be the best for many decades (50.5% used and 49.5% lost). These were the last years of the relatively efficient, high-compression automobile engines that required tetraethyl lead in gasoline. Also, the country had not embarked on efforts to clean up internal combustion engines or electric power production facilities, with the resulting penalty in fuel consumption efficiency.

Energy Flow—1975

Figure 1.5 shows the total U.S. energy system in 1975. It is important to look more closely at this system in light of two significant events—the Arab oil embargo of 1973–1974 and the business recession of 1974–1975.

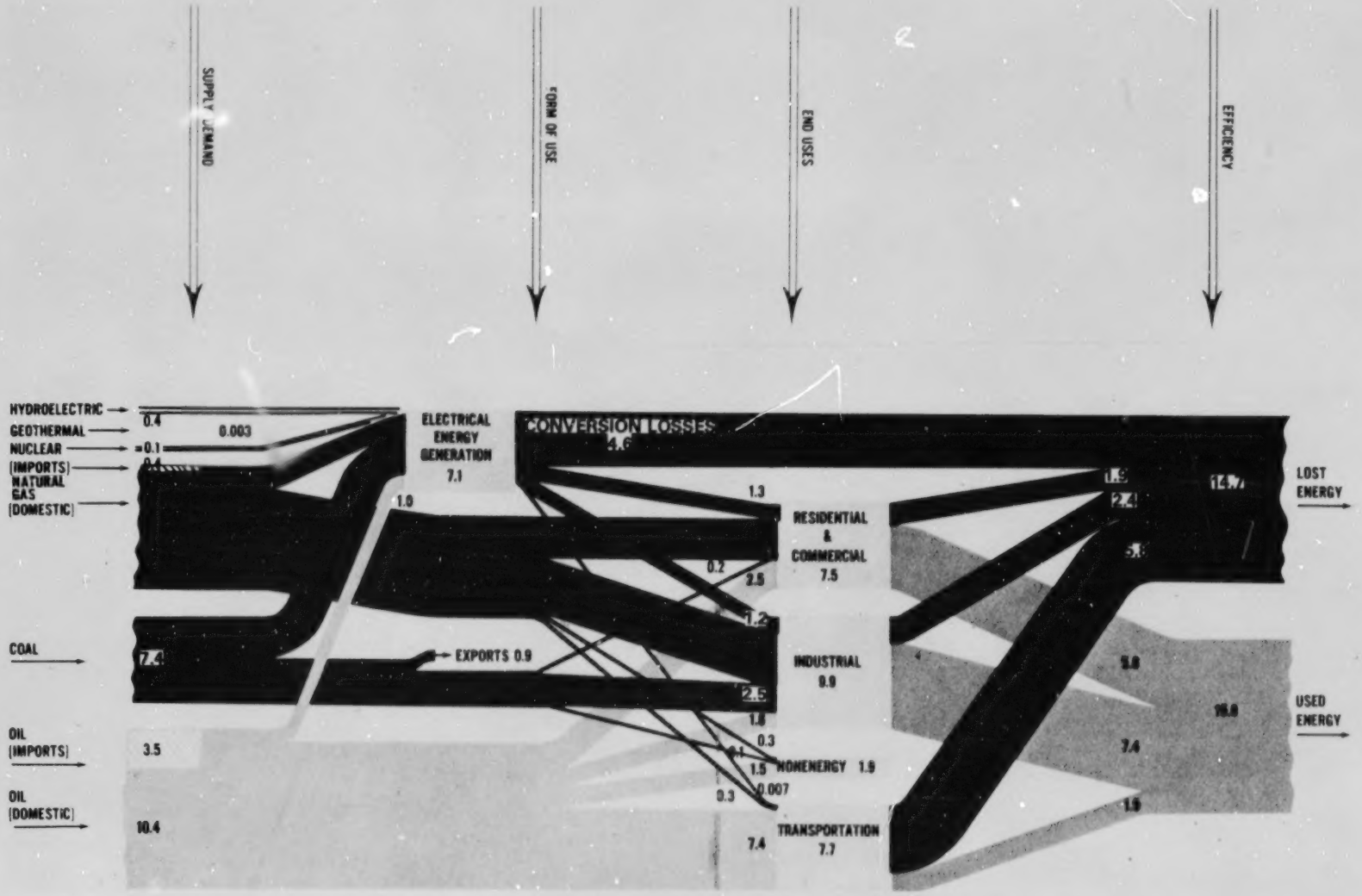

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Figure 1.4. Energy Flow—1970

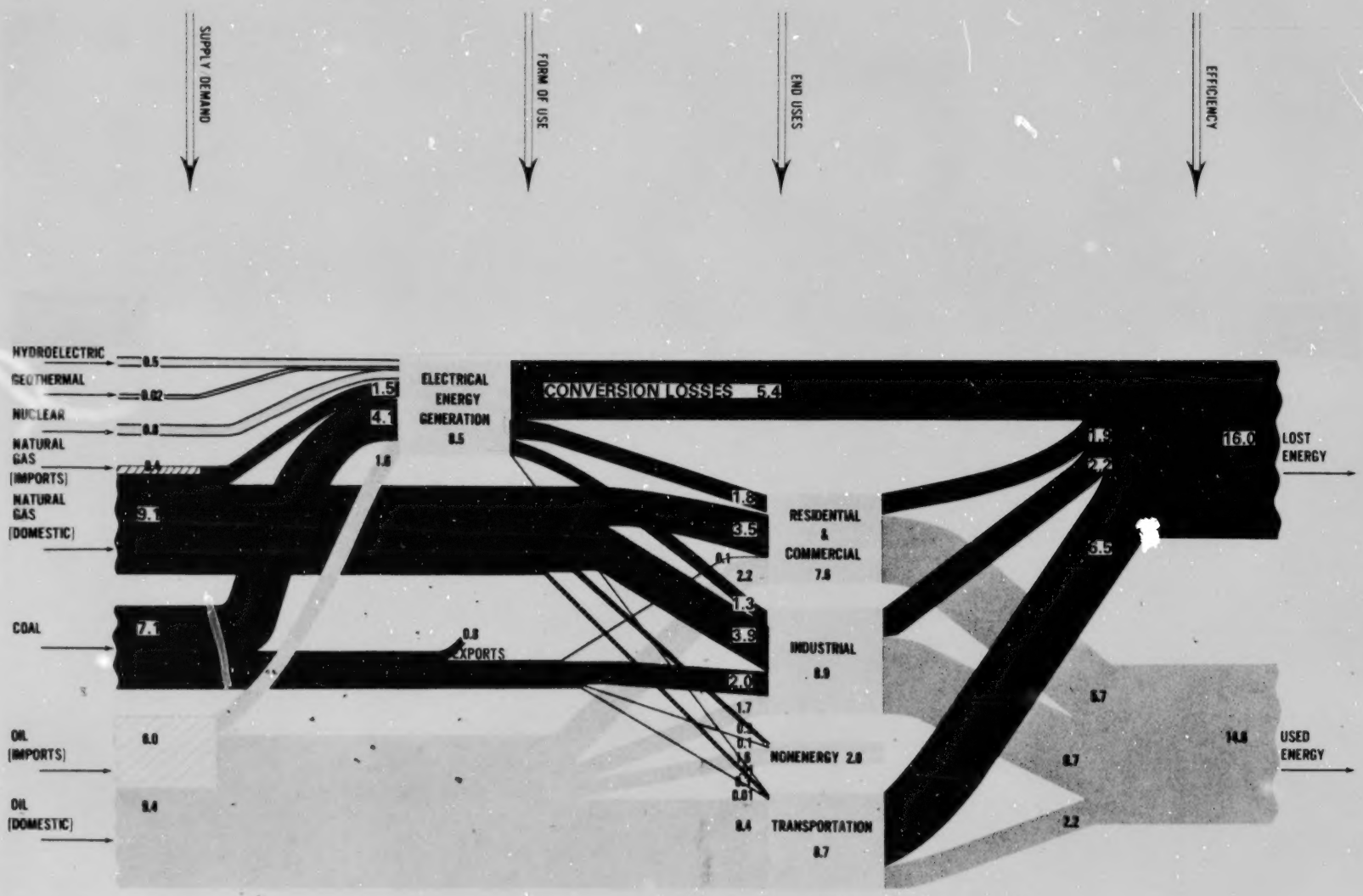

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Figure 1.5. Energy Flow—1975

Comparing the 1975 energy flow figure with that for 1970, it is apparent that the rate of growth during this interval is considerably less than that of previous years (in fact, energy demand actually declined slightly during 1974 and 1975). This decline reflects several forces such as the economic downturn, higher fuel prices, and conservation efforts.

While demand was held somewhat in check, domestic production of oil and natural gas declined mainly because of dwindling resources. In fact, both oil and natural gas experienced decreases of more than one million barrels per day from 1970 levels. This decreasing supply resulted in a rapid increase in oil imports as well as some growth in U.S. imports of natural gas.

The mix of fuels put into electrical energy generation shows an interesting shift. In 1975, the U.S. was using considerably more oil and nuclear fuel in its generating plants; coal and hydroelectricity increased slightly, while the use of natural gas declined. This was the result of a conscious effort under government direction to reduce the use of natural gas as an electric generating fuel; again, this effort was a reaction to dwindling U.S. gas reserves.

In examining energy end use in 1975, it is readily apparent that industrial use of energy declined (natural gas was most affected, while the use of oil and electrical energy increased slightly). The use of energy in transportation and in residential and commercial showed some growth over 1970 levels.

Industry took the brunt of the 1974–1975 recession, while the use of energy in transportation grew, increasing dependence on oil, which could no longer be easily provided from domestic sources. Thus, by the end of 1975, the U.S. was more dependent than ever on imported oil.

Projected Energy Flow—1980

Although nothing will alter past energy use patterns, the energy future is a different matter. The state of technology and the availability of different fuels can be changed, but in an energy system as large as that developed by the U.S., change will not come quickly. The public will have to expend much time and effort if it decides to reverse the trends of past years.

The projection of U.S. energy flow for 1980 is a composite of several widely used forecasts made by government agencies, industry, and private organizations. On the supply and demand side, figure 1.6 projects that use of all fuels may increase for 1980. Oil use is projected to increase by nearly 30% over 1970, with the bulk of this increase supplied through imports. In fact, by 1980 it is possible that the U.S. will be more dependent on foreign oil than in 1970. Coal use is projected to increase by 27% over 1970, while natural gas use would increase only slightly. Comparing 1970 and 1980, domestic natural gas production is projected to decline by almost 3%, while natural gas imports may increase threefold. Nuclear energy is projected to increase 28 times over 1970, yet in 1980 it will comprise only 7% of total energy input. Less significant in terms of energy input are geothermal and solar energy. In 1980 these may add 0.7% to energy supplies. Hydroelectric power is expected to increase by 50% over 1970.

Electrical energy generation is predicted to increase by about 70% between 1970 and 1980; coal may still provide the bulk of the supply, but nuclear energy would replace natural gas as the second largest source. It is in this decade that technology will make available new conversion processes. Coal-gas produced by converting coal to synthetic natural gas (a process known as coal gasification), oil-gas, produced by converting oil to synthetic gas, and coal-oil, produced by converting coal to synthetic oil (called coal liquefaction), would all be used to help meet energy needs. However, these processes will not result in energy salvation in 1980; as the figure indicates, such processes would contribute very little toward total energy supply (only about 1% of energy needs). As for electricity, there is also a conversion penalty to pay for these processes: one-third of their fuel potential is estimated to be lost in conversion.

Figure 1.6 also points out that, in 1980, transportation would use nearly 25% more energy than in 1970 and that it would still depend on oil for over 95% of its needs, not significantly different from 1970. There are several reasons for this lack of change: it will take a considerable amount of time to develop modes of transportation that do not depend on liquid fossil fuels, and if past experience with automobile replacement is any indication of what

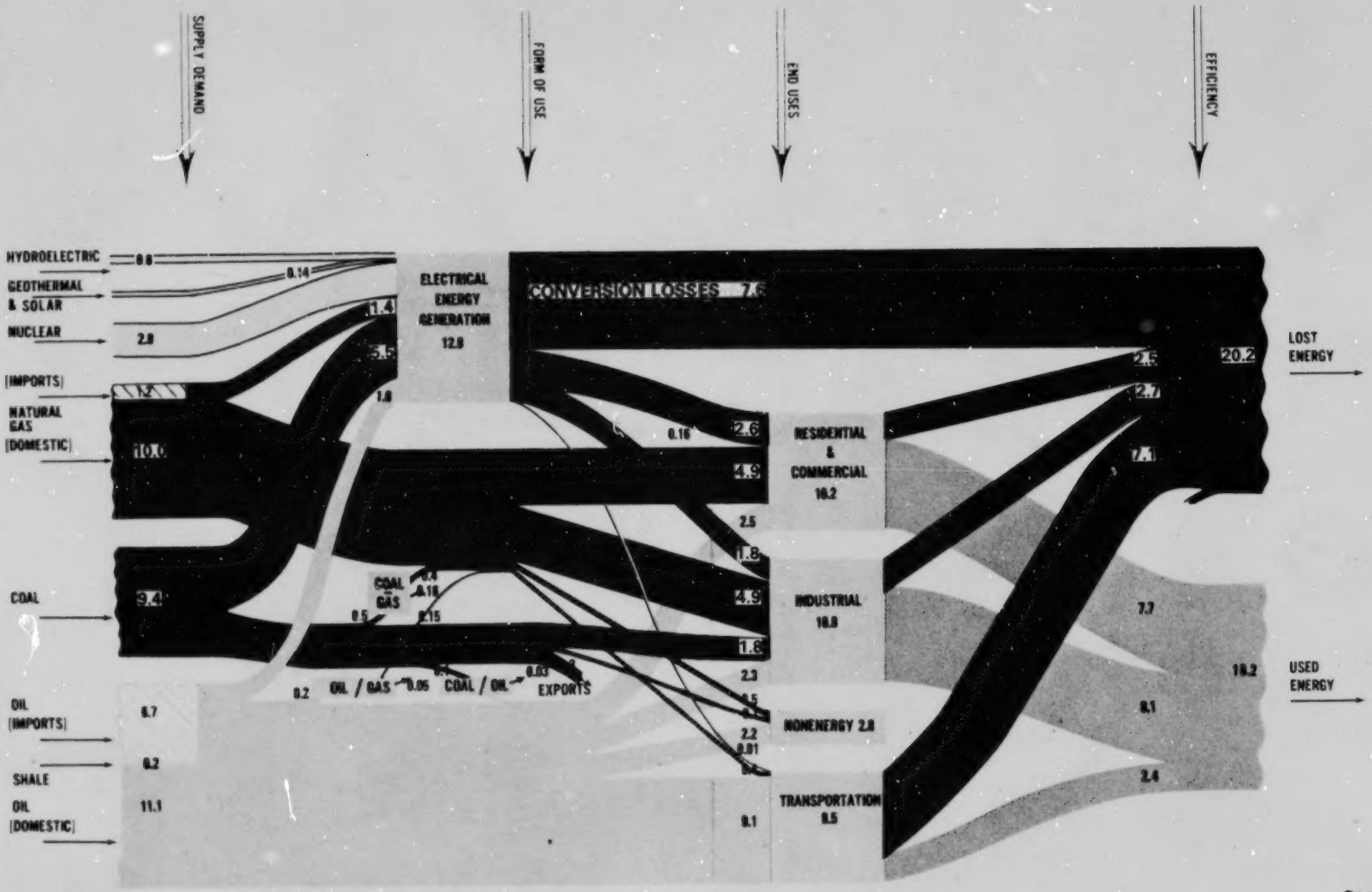

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Figure 1.6. Energy Flow—1980

can be expected by 1980, three out of four automobiles now on the road will still be there in 1980.

Non-energy shows the most growth of the end uses during this decade. Increasing use of plastics, fertilizers, and petrochemicals will lead to an increase in this sector of almost 50% between 1970 and 1980.

Industrial end use is projected to grow by only 9% from 1970 to 1980; this increase is extremely low, perhaps unrealistically low. However, it is assumed that higher fuel and energy costs will stimulate effective conservation efforts that will reduce waste and loss without seriously disrupting industrial activity. Residential and commercial is predicted to grow by 36% from 1970 to 1980, with the use of coal to this sector disappearing, and the use of oil remaining constant. The increase in this sector is provided by electricity, which doubles, and by natural gas.

Unlike the situation in 1970, used energy will be less than lost energy in 1980, when the country will be using only 47% of its energy efficiently. The bulk of the lost energy—almost 75%—comes from transportation and electrical energy generation. With current technology and with a greater emphasis on electrical energy, this increase in the relative inefficiency of the total energy system is not surprising.

Projected Energy Flow—1990

Figure 1.7 is a projection of the U.S. energy system as it might appear in 1990; much of what is present today will still exist then.

It is projected that the U.S. would use 24% more fuel in 1990 than was projected for 1980, and about 60% more than in 1970. That is also the decade when the limited capacity of domestic oil and natural gas supplies becomes most evident. From 1980 through 1990 the demand for oil is projected to grow slowly, while domestic oil production is expected to decline slightly. This drop occurs even with the Alaskan pipeline and the projected oil shale production adding to the domestic supply. Therefore, imports will increase, making the country dependent on foreign sources for nearly half of the oil in 1990.

The demand for coal is estimated to be 29% above 1980 levels. Electrical energy generation would still be the major market for coal in 1990. However, direct use of coal in industry, 3.0 MB/DOE, is projected to be the highest in the 30-year period of this analysis. Coal-gas and coal-oil show a threefold increase over 1980, but still constitute only a small part of the coal used.

Domestic natural gas use would continue its downward trend, declining by 15% between 1980 and 1990. This is due to limited supply rather than to decreasing demand. Even though natural gas imports will increase 17%, natural gas use will fall by 12%.

Almost all projections show significant increases in nuclear energy by 1990; the more optimistic ones predict a 250% increase over 1980. This is one area where action or lack of action will prove to be important. It is technically possible to accomplish this increase, but a decision to do so will be required. Due to the long time involved in the planning and construction of nuclear plants (8 to 10 years), if action is not taken by 1980, nuclear power will have already become eliminated as a major energy option from the 1990 energy system.

Geothermal and solar energy are projected to grow by 167% over 1980 as their technology emerges from its infancy. But for hydroelectric energy, it is predicted that by 1980 most major sites will have been used, and therefore no additional growth is forecast for 1990.

Electrical energy generation is projected to continue to grow. In 1990 it is predicted to be over half again as large as the 1980 level, and over twice as large as that of 1970. By 1990 nuclear energy will supply over half the input for electrical generation, with coal being second. Other conversion processes such as coal gasification are projected to increase in 1990 to reach the equivalent of 1.7 MB/DOE of synthetic natural gas production and 0.8 MB/DOE of synthetic crude oil.

In energy end use, transportation will still depend primarily on oil, and non-energy will continue its rapid growth. As it is assumed that most of the easy and less costly conservation measures will already have been implemented by 1980, industrial use of energy would begin to increase. In 1990 the industrial fuel mix shows a trend likely to become stronger: the use of natural gas and oil declining, with direct use of coal and electrical energy becoming far more important. By 1990 new

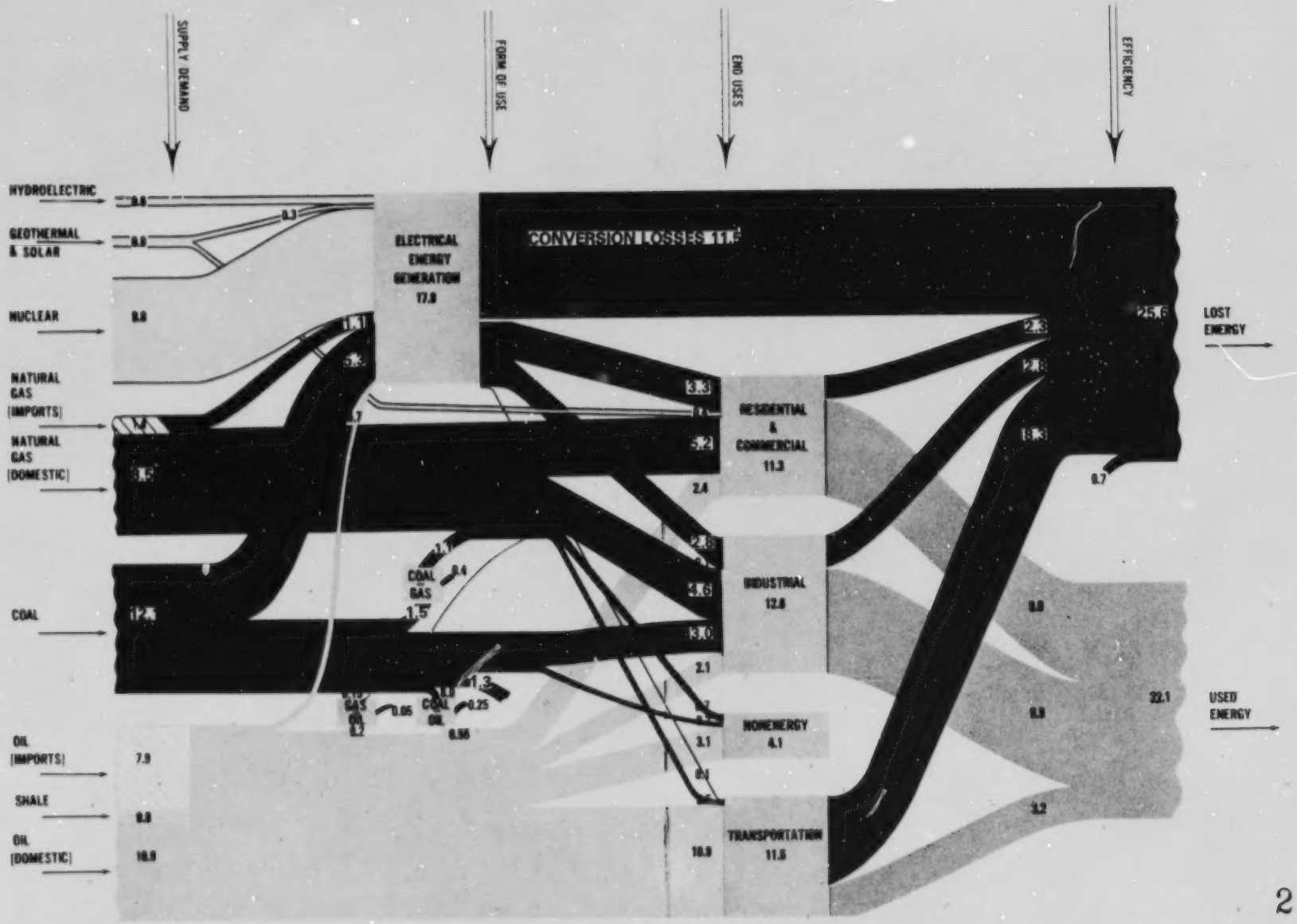

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Figure 1.7. Energy Flow—1990

household formations, which grew at a high rate during the 1970s and early 1980s as a consequence of the baby boom of the late 1940s and 1950s, are expected to drop to lower levels; therefore, a relatively low increase in the fuel use of residential and commercial is projected.

Completing the examination of the projection for 1990, it will be noted that the U.S. would still lose more energy (54%) than it would use (46%). This energy efficiency in 1990 reflects increasing reliance on electrical energy generation.

Recent Growth Patterns

Figures 1.3 through 1.7 reveal important trends in certain energy factors. All charts are drawn to the same scale, so the dimensional changes represent actual growth patterns in a period of 30 years. Using this scale, a chart representing the flow patterns for 1940 would be about 53% of the size of the one for 1960, and the one for 1950 would be about 75% of the size of the one for 1960. Somewhere in the mid-1950s the U.S. embarked on its energy-consuming growth, which laid the foundation for much of the energy dilemma. The graphical data project a fivefold increase in electric generating capacity from the year 1960 to 1990 (3.4 MB/DOE of supplied energy in 1960 up to at least 17.8 MB/DOE in 1990).

Trends indicate that from the year 1970 through about 1982 or 1983, the U.S. will use as much oil and gas as it had used from the beginning of its history until the year 1970. To compound the problem, much of the rest of the world now has energy consumption patterns that are growing at a faster rate than that of the U.S. It appears that the world will use as much energy from all forms between 1970 and the year 2000 as it did from its creation until 1970.

Figure 1.8 provides a long-run perspective of U.S. energy supply and demand from 1900 to 1975 and projected to 2050. From 1900 through the 1960s the country had an energy surplus. In fact, during much of this time the U.S. possessed a considerable volume of shut-in oil and natural gas productive capability. Throughout the 1960s this excess capacity was rapidly used up as the demand for energy increased at a high rate. By 1970 the country had reached a point where it crossed over from an energy surplus to an energy deficit. Furthermore, the rate at which demand increased ahead of supply caused the U.S. to use imported fossil fuels.

The figure shows the deficiency of the energy supply system beginning in the early 1970s. Since the U.S. is not yet ready to replace its faltering fuel supply with nonfossil energy sources, it is forced to import fossil fuels, particularly oil. This figure also points out the difference between the era of relatively cheap and abundant energy, which is ending, and the emerging era of increased need for new and expensive nonfossil energy supplies and imported fossil fuels. Even a sizable decrease in energy demand and a major increase in domestic fossil fuel supplies would provide a respite of only a few years in the national energy dilemma.

The U.S. finds itself in the twilight of the fossil fuel age. It has used its oil, gas, and coal resources as one of the building blocks of its technical industrial society, and will now have to use its technical capacity to carry itself into the next energy age.

The Special Role of Oil

Given the importance of oil in the U.S. energy system and the predicted continued reliance on this fuel in the future, it is worthwhile to examine some of the reasons behind the rapid growth in its use and the effect this growth has had on oil supplies.

Oil in quantity was discovered a little more than 100 years ago, with its initial use being primarily for lighting in the form of kerosene. By the beginning of the 20th century the demand for kerosene was surpassed by the demand for gasoline for use in the automobile, and oil was accordingly assured a steady and constantly growing role in the U.S. economy.

It was not only the automobile, but also the special properties of oil that caused it to be an attractive energy source. Crude oil and the products refined from it were much easier to *handle*, *transport*, and thus *control* than other fuels such as coal. Oil was also accessible, and it was relatively inexpensive when compared to other available energy sources. Developing countries thus turned to oil to fuel their economic systems and to provide the necessities

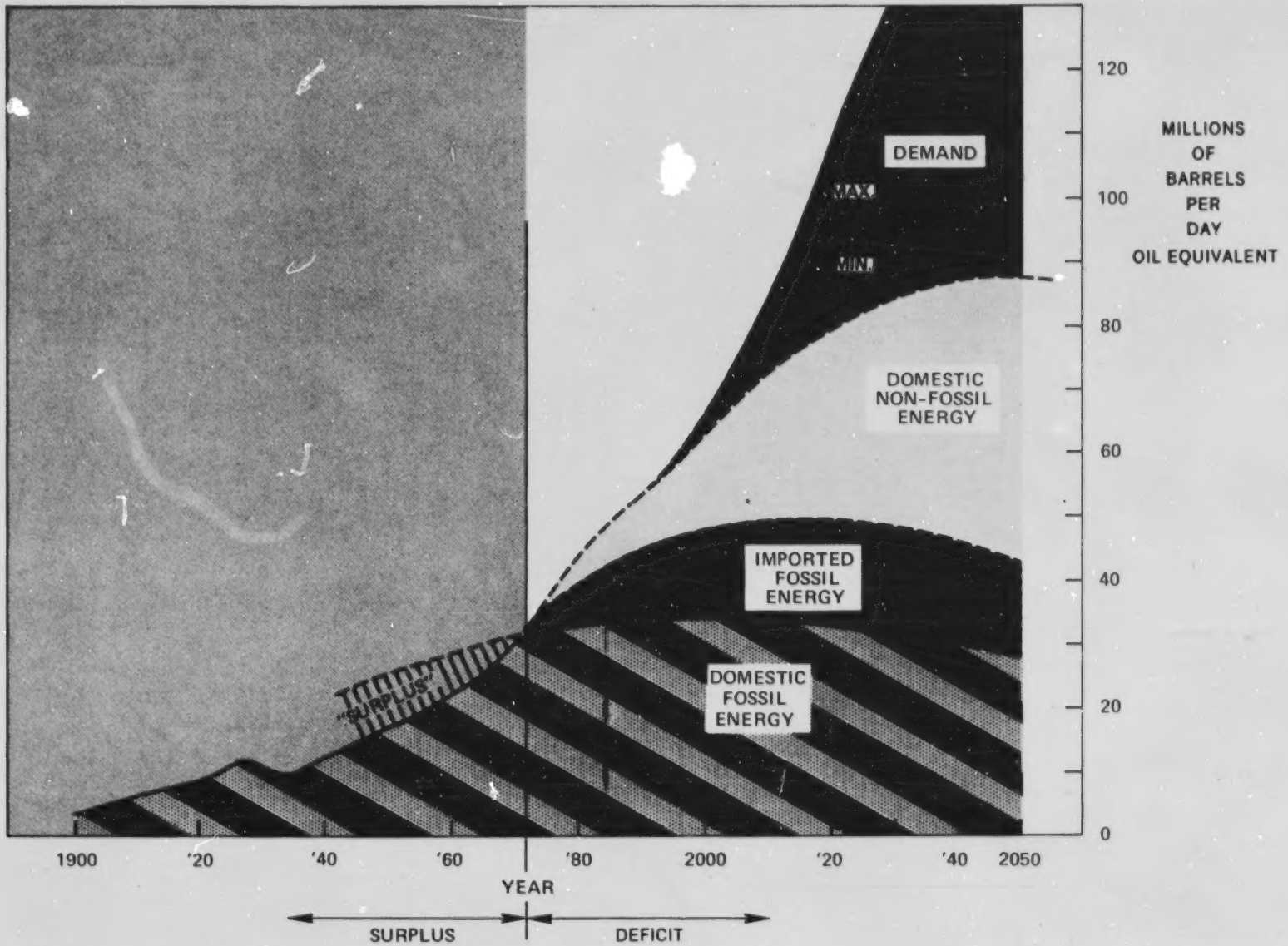

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Figure 1.8. Supply and Demand—1900 to 2050

of life such as food, clothing, and shelter, while industrialized countries, in particular western Europe, turned to oil to meet the demands of the industrialized age. Oil became the "growth" fuel of the 20th century.

Oil Flows

There has been a 7% average annual growth rate for oil, compared with 3.5% for fuels in general. In the first part of the 20th century, the U.S. was the prime supplier of oil. In fact, the U.S. supplied two-thirds of the world's petroleum exports through 1950, and it still ranks as the all-time leading exporter of oil, even though it has stopped exporting and, in fact, has been importing significant quantities of this fuel since the embargo. In 1946, about one million barrels of oil per day moved in international trade, and the United States, South America, and the Middle East were the prime exporters.

By 1972, the one million barrels had increased to 30 million barrels. More importantly, the U.S. demand for oil has surpassed its ability to provide it, resulting in the need to import oil from South America, Africa, and the Middle East. It was this inability to keep pace with the growing need for oil supplies and the concurrent inability to hold in check this growing demand for oil that brought the U.S. into the "crisis" of 1973, when the Organization of Petroleum Exporting Countries (OPEC) imposed an embargo.

During the three months of the embargo, it became clearer than it had in the past that the industrial world was prepared to pay much more for oil than it had been paying. Oil costing as little as 20¢/barrel to produce rose to a level of $11/barrel, as shown in figure 1.9. This means that between 1972 and 1975, the price of the world's "growth fuel" rose from 50¢/million Btu's to $2.00/million Btu's.

After the Embargo

The figures shown earlier indicate that the U.S. has grown to depend on oil for almost 50% of its total energy needs and that unless significant steps are taken, it is expected to continue to require a significant proportion of oil through the end of the century. Since the country does not have enough domestic petroleum to sustain this requirement, it is critical that the traditional patterns of U.S. energy use be changed.

This change must occur for several reasons:

1. A *boycott* of overseas petroleum could be much more serious now than before due to increasing dependence on foreign oil. In 1972 this dependence was 14% of total U.S. energy needs; in 1975 it was about 20% and is still growing. Thus, a state of energy independence remains a distant dream and another embargo by OPEC a stark reality.
2. The *development of alternative energy sources* has been retarded for several reasons:
   a. Questions of nuclear safety, strip mining of coal, and oil drilling on the continental shelf cause concern for protection of the environment.

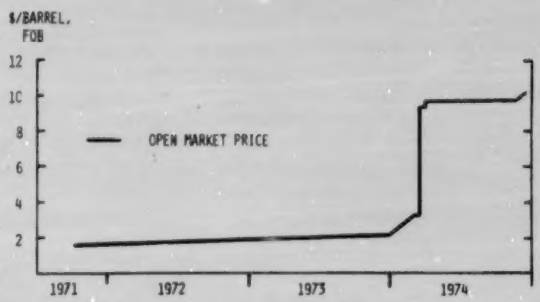


Figure 1.9. Oil Price Increases

   b. Scarcity of capital and high rates of interest often make the cost of conversion from one source of energy to another prohibitive.
   c. Pollution regulations in certain areas often make it difficult to change to alternate energy sources such as coal.
3. The *price* of all fuels, and oil in particular, has risen dramatically. Colleges and universities as well as other consumers cannot afford to pay the price of continued high rates of consumption if there is to be enough money left over to sustain programs and people.

A large, complex energy system has been created over a long period of time, and is thus difficult to stop or to redirect. But it must be redirected, and colleges and universities have an important role in such change.

2

Energy: Its Conversion, Use, and Waste

Conservation of energy is synonymous with elimination of energy waste. Thus, it is necessary to explore the kinds of waste that may be occurring in institutions of higher education and to evaluate the potential monetary returns that would accrue from waste elimination. By investigating how energy is consumed on the campus, the division of jobs performed by energy, and the amount of energy wasted, a better understanding of the potential for reduction of energy consumption will be gained.

Figure 2.1 displays a before-and-after situation at Ohio State University. Remarkable savings have been realized in this building, which is a clinical administrative facility with a variety of mechanical systems. While energy consumption reductions of this magnitude are not always possible in each building, the opportunity exists at most colleges and universities to realize reductions of 25% to 40%.

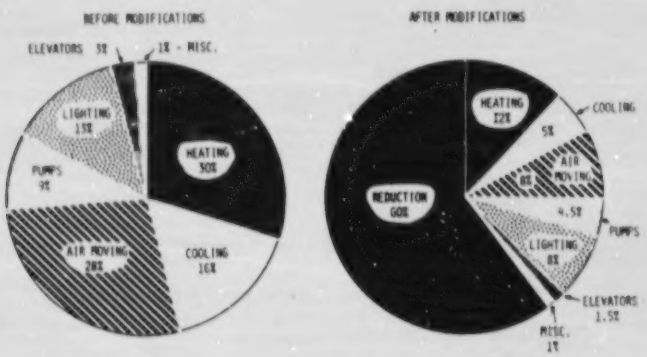


Figure 2.1. Annual Energy Consumption for a Building (in Dollars)

It might be asked: If these savings are possible, why were they not sought before? In fairness to most physical plant personnel, there has always been an awareness of potential savings and of potential investments that would improve the plant. It is the rise in the prices of fuels, caused by the factors discussed in chapter 1, that has moved the profitability of plant economics from what was often a borderline situation to one that is clearly a prudent investment.

In order to discuss energy systems and to make judgments about what can be saved, what should be saved, and what types of energy-conserving measures should be implemented, a review of energy in its various forms will be useful.

Forms of Energy

It is conventional to express heat energy in millions of Btu's; a Btu, or British thermal unit, is the quantity of heat required to raise the temperature of a pound of water one degree Fahrenheit. As an example, a small house would use one million Btu's for space heating on a day in which the temperature outside averaged 30°F. Similarly, electricity can also be expressed in Btu's, but the more common unit is the kilowatt-hour (kWh). One kWh would

keep a 100-watt bulb burning for 10 hours, or it would be used in an electric kettle to bring three gallons of water to the boil.

For this discussion it is convenient to look at energy in primary forms (fuels) and in secondary forms (steam and electricity). Each of these forms contains energy, and a certain number of Btu's can be assigned as a measure of the energy in these forms. However, there is a hierarchy wherein one million Btu's of electricity is worth more than one million Btu's of steam, and one million Btu's of steam is worth more than one million Btu's of fuel. Figures 2.2 and 2.3 explain this hierarchy: (1) fuel can provide heat, (2) steam can provide heat and mechanical work, and (3) electricity can provide heat, mechanical work, and light.

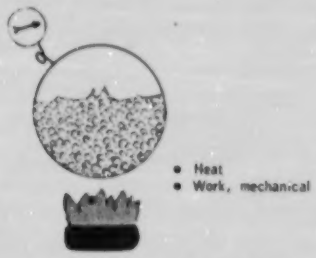


Figure 2.2. Steam Energy

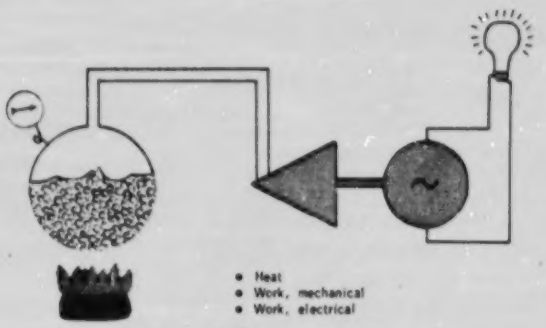


Figure 2.3. Electrical Energy

At 1976 energy prices, the average institution paid for these energy forms in the range of $2 per million Btu's for fuel heat and 2.5¢ per kWh for electrical energy, which is equivalent to $7 per million Btu's. However, energy prices are not constant and are not the same over all parts of the country, as illustrated in table 2.1.

Table 2.1 provides highlights of a survey made by the University of Colorado at Boulder in February 1976. Notable are the very low price for electricity in Washington State and the higher price in Massachusetts. Electricity in the West is from hydropower, that in the East from imported, low-sulfur fuel oil. The average price for fuel oil was close to the figure of $2/million Btu's used earlier, and gas ranged from 56.9¢ to $1.62/million Btu's.

The principal reason for discussing the possibilities and problems inherent in energy management is the fact that prices for fuels increased dramatically in the first half of the 1970s. Prior to 1970 there was an abundance of fuel available at 30¢ to 50¢/million Btu's, and the electricity produced from this fuel was closer to 1¢/kWh than to 2.5¢.

How Energy Is Used and Wasted

While some fuels may be used directly to heat buildings on the campus, most fuel energy is converted to steam in boilers, which can then be used for heating, cooling, and occasionally for driving steam turbines. Similarly, electricity is used on the campus for lighting, driving fans, and for ventilation, as well as for driving motors on various types of machinery.

In a typical university budget for fuel and electricity, on a dollar basis approximately

TABLE 2.1
Energy Costs at Selected Universities in February 1976

	Electricity $/kWh	Natural Gas, Interruptible $/Million Btu's	Fuel Oil (No. 6) $/Million Btu's
University of California	0.0175	1.57	2.28 (No. 5)
University of Colorado	0.0166	0.569	1.92
Cornell University	0.0225	1.416	1.957
Duke University	0.018	—	2.022
University of Florida	0.0262	0.8341	1.732
University of Illinois	0.0143 (own standby)	—	2.103 (No. 2)
Massachusetts Institute of Technology	0.034	1.553	1.957
University of Minnesota	0.021	0.8731 (winter)	2.175 (No. 2 standby)
University of Washington	0.007	1.62	1.806

equal amounts of the two forms of energy are purchased (see figure 2.4). The portion of electricity used for lighting is about 28%, whereas that used for heating, ventilating, and air conditioning (HVAC) systems and supplementing air conditioning totals 62%. The other 10%, labeled "miscellaneous," is for laboratory equipment, computers, printing presses, visual aids, household-type appliances such as TV and radio, and elevators and escalators.

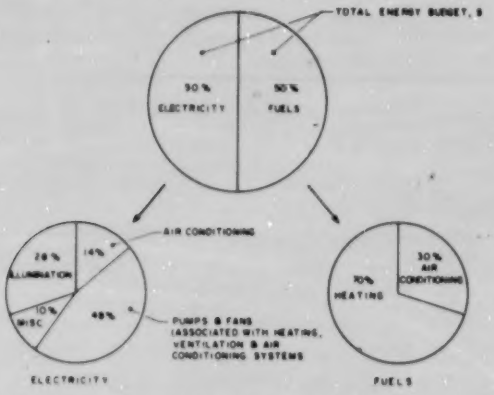


Figure 2.4. One University's Energy Budget

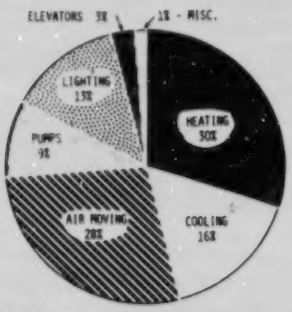


Figure 2.5. Annual Energy Consumption for a Building (in Dollars)

Figure 2.5, a diagram from Ohio State, shows some of the energy functions for a single building as a percentage of all energy purchased (electricity plus fuel). Lighting at 13% corresponds to the 28% shown in figure 2.4, since electricity represents about half of the total energy dollars. Thirteen percent of the total is 26% of the electrical half. Elevators used 3% of the total energy before Ohio State's conservation program in this facilitity was put into force. Eighty-three percent of the total energy is used for air moving, pumps, heating, and cooling.

Another way of looking at individual building energy consumption is in terms of energy units: Btu's and kWh's. One science building at M.I.T., with 130,000 square feet of total space, has an annual energy use of:

6 million kWh's of electricity,
35 billion Btu's of steam heat, and
2 million ton-hours of chilled water.

Expressed in the same units, Btu's, these quantities are:

20 billion Btu's electricty,
35 billion Btu's of heat, and
25 billion Btu's "chill."

On a square foot per year basis:

Electricity	157,000 Btu's (46 kWh)
Heat	270,000 Btu's
Chill	190,000 Btu's
Total	617,000 Btu's

In more southern locations, the heat and chill quantities would be reversed, but the fact that college and university facilities consume considerable energy is apparent from this analysis.

As noted earlier, this use of energy is synonymous with waste of energy, no matter how efficient the use. That is, the conversion of fuel to steam or electricity and the subsequent use of steam and electricity necessarily involve the loss of Btu's. There is, however, a considerable degree of difference between the number of Btu's lost through the *efficient* generation, distribution, and end use of energy and that lost through *inefficient* generation, distribution, and end use. An examination of boiler and steam systems as well as some of the HVAC systems used on campus will be helpful in gaining a better understanding of the degree of energy use and waste. More important, this type of examination will quickly point out ways in which such systems may be modified to make them more efficient, thereby reducing energy waste and cost.

It is important to understand how energy is used and wasted in typical energy conversion processes:

1. The conversion of fuel into steam or hot water (boilers).
2. The conversion of steam or electricity into chilled water (chillers).
3. The conversion of fuel or steam into electricity (generators).

The use and waste of energy at the end of the energy chain is also important, that is, where the energy comes in contact with the people it is intended to serve, in the form of heating, cooling, or lighting. This topic will be discussed later.

Boilers

Figure 2.6 illustrates a simplified boiler and steam system. The fuel is burned and releases its energy to a body of boiling water. The steam so produced travels through the steam line to the equipment where it is to be used; the steam turns back to water in that equipment, shown in the diagram as a steam coil, and the water is separated out by a device known as a steam trap. From that point the water (called condensate) may or may not be brought back to the boiler. The overall efficiency of the steam system is likely to be about 70%.

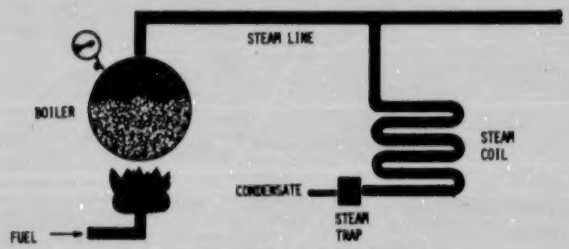


Figure 2.6. Boiler and Steam System

In a steam system, fuel is converted into steam at a boiler, and this conversion entails a certain loss of energy. The fuel then has to be transported by a steam line to the point at which it is to be used, and thus further loss occurs. There are also certain restrictions on the amount of heat that can be abstracted from the steam at the point of use. Ultimately, the steam turns to hot water again (condensate), and a decision must be made as to whether this condensate should be brought back to the boiler to recapture the heat in it, or whether (if the point of use is distant from the boiler) the water should be discarded. Such elements as the cost of make-up water and chemicals used to treat the water should also be considered.

In summary, energy losses in a steam system are as follows (see figure 2.7): although 100% fuel energy enters the boiler, 20% to 25% is lost to the stack, leaving 75% to 80% in the steam; another 10% to 20% of the heat left in the steam may be lost in transmission from the boiler, or in condensate returning to the boiler; the net result is that, of 100 units of fuel energy going into the boiler, only 60% to 72% may arrive at the point of use. A figure of 70% will be used for discussion in this chapter, but boiler efficiency can actually vary between 65% and 85% depending on the design, control instrumentation, and fuel used.

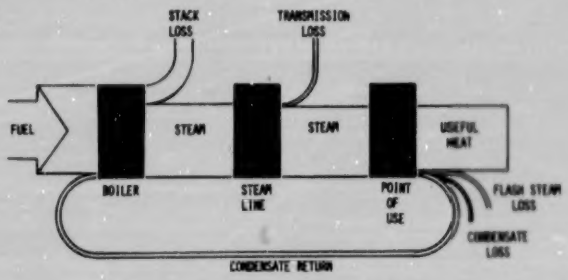


Figure 2.7. Steam System Efficiency

Boiler efficiency can be easily estimated from a chemical analysis of the gas going up the stack and from the temperature of that gas. It is strongly recommended that this type of measurement be undertaken; the total cost of instruments to perform the analysis is about $200 (the techniques used are provided in appendix A-1). Improvements are made by reducing the amount of air used to burn the fuel, and by reducing as far as possible the stack temperature of the gases leaving the boiler.

Different fuels have different optimum efficiencies at the boiler, as indicated in table 2.2.

TABLE 2.2
Optimum Boiler Efficiencies

Coal, pulverized	85%
Coal, stoker	75%
Heavy fuel oil	85%
Distillate oil	85%
Natural gas	82%
Sawdust and wastes	65%

If the efficiencies determined by gas analysis and temperature are below these figures, consideration should be given to improving the boiler plant. An improvement of one percent at the boiler plant yields savings in every phase of steam use—for a high-energy-end-use facility like a science building or for a dormitory. A one percent improvement at the boiler results in a one percent reduction of the total fuel bill.

Chillers

Chilled water is used as the medium for extracting heat and moisture from air during the air conditioning mode of an HVAC system. There are two ways of producing the chill effect:

1. *Compression cycles*, in which a refrigerant is forced to liquefy and subsequently evaporate and cause a chill. Such compressors are driven by electric motors and can also be driven by steam turbines.
2. *Absorption cycles*, in which water is forced to evaporate to produce the "chill" and is then restored to its liquid condition by absorption in lithium bromide solution. Heat energy, normally in the form of hot water or steam, is used as the energy input to this type of cycle.

Just as there are certain inherent wastes in the production of steam, there are inherent losses in producing chilled water.

There are three principal ways of obtaining chilled water using the absorption and compression cycles discussed above:

1. From steam or hot water in an *absorption* system. Generally speaking, it takes 20 pounds of steam (20,000 Btu's) to make one ton of cooling (12,000 Btu's/hour).
2. From steam in a steam-driven *centrifugal* system. As little as eight pounds of steam may produce a ton of cooling in a condensing system. As much as 30 or 40 pounds may be needed to do the same job in a back-pressure system, which at first may appear wasteful. But if there is a use for the exhaust steam flowing from such back-pressure turbines, this type of system is the most efficient of all.
3. From *electricity*, using electric motors to drive centrifugal or reciprocating compressors. Using the centrifugal compressor, one million Btu's of chill (83 ton-hours of cooling) can be extracted with the expenditure of 340,000 Btu's (100 kWh's). This would apply for equipment rated at 1.2 kW's/ton of cooling. More efficient equipment can produce a ton of cooling for 0.8 kW. In that case 1,500,000 Btu's of chill could be extracted with the expenditure of 100 kWh's. The reciprocating compressors are less efficient.

Obviously, this is an area in which expertise is needed to make proper decisions; however, a brief discussion in terms of dollar costs should help clarify the situation.

In terms of thermal efficiency, the centrifugal compression cycle is the best of the three. In terms of dollars, it depends on respective energy prices. At the prices being used for this discussion, 1.0 kWh of electricity (2.5¢) produces one ton-hour of cooling with a centrifugal compressor; and 20,000 Btu's of steam, i.e., 28,500 Btu's of fuel energy (6¢) produces one ton-hour of cooling with an absorption unit. (The ratio 20,000/28,500 is the 70% efficiency of the steam system.) Thus, electricity-driven centrifugals produce cooling for a lower cost.

To help define the ton-hour term, it should be noted that three tons of cooling is sufficient to maintain a suburban house at 75°F with an outside temperature of about 95°F. That is, three ton-hours of cooling is sufficient to cool the house for a one-hour period.

Production of Electricity

Very few colleges and universities generate their own electricity; most buy it from a public utility. Nevertheless, it is helpful to review the waste of energy that occurs when fuel energy is turned into electrical energy since, as noted in chapter 1, this waste is a large part of the national loss of energy.

As mentioned previously, conversion of fuel energy into electricity raises it from "low-grade energy" to "high-grade energy." A good lighting system cannot be designed to run directly on fuel, whether natural gas, fuel oil, or coal, but an efficient lighting system can be run on electricity. Therefore, situations in which waste resulting from conversion of fuel into electricity must be tolerated to profit from the special properties of electricity.

An efficient power station can produce about 100 kWh of electricity from one million Btu's of fuel energy, i.e., one million Btu's is converted into 340,000 Btu's of electricity. These 340,000 Btu's are capable of performing work that the one million Btu's could not do, such as raising elevators, lighting lamps, operating computers, and, in the case of air conditioning, "pumping" one million Btu's out of water to produce chilled water. These uses of electricity give a clue to two kinds of waste that exist: (1) waste in converting one form of energy

into a higher-grade form, as shown in figure 2.8, and (2) distribution waste, due to poor power factor in electrical distribution systems, which causes additional line loss, but can be corrected by installation of capacitors and proper sizing of motors (see chapter 5).

Steam System Distribution Losses

Energy loss also occurs in the steam, hot water, or chilled water distribution system. Here, the best advice is to insulate the lines. At 1976 fuel prices, it is a safe assumption that 1½ inches of fiberglass will be a good investment, with less than a two-year payout.

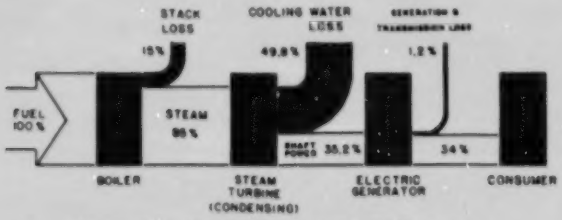


Figure 2.8. Electric Generation Efficiency

Capturing heat loss through a steam distribution system also involves a decision on what to do with the condensate. On average, the condensate carries 15% of the heat entering the boiler. At 1976 fuel prices, condensate might be valued (in its hot condition) at 45¢/1,000 lbs. Thus, if the boiler is close to the end use of the steam, it almost certainly is worth recovering the condensate in an *insulated* system. If the point of use is far removed, this type of recovery is questionable. And as mentioned earlier, the cost of make-up water and chemicals for treating the water should also be included.

The piece of equipment that separates the condensate from the steam is called a steam trap. Steam traps must be properly maintained, because a leaky trap is the same as a leak in the steam line. Certain industries have found that a fuel savings of 15% could be realized by improving the maintenance of steam traps.

Leaks from traps, valves, and flanges are, of course, a visible manifestation of loss. Table 2.3 shows the cost of various sizes of steam leaks at 100 psig, using a steam value of $3/1,000 lbs. This is in proportion to the overall system efficiency of 70% mentioned earlier and a fuel value of $2/thousand Btu's.

Energy End Use and Waste

The use and waste of energy at the end of the typical campus energy chain offers much potential for consumption reduction. As noted earlier in the Ohio State example, 73% of the total energy used in the building discussed was for air moving, pumps, heating, and cooling, or, in other words, for heating, ventilating, and air conditioning. The systems that utilize energy for these functions—commonly referred to as HVAC systems—afford accurate and consistent temperature control by continually heating and cooling air to maintain a selected temperature. Often, this simultaneous heating and cooling may be minimized or eliminated, yielding signicant savings of energy without a loss of comfort or threat to safety.

TABLE 2.3
Cost of Various Sizes of Steam Leaks at 100 psig
(Using a Value of $3/1,000 Lbs.)

Size of Orifice	Lbs. of Steam Wasted/Month	Cost/ Month
½"	835,000	$2,500
⅜"	470,000	1,400
¼"	210,000	630
⅛"	52,500	157

An examination of some of the HVAC systems used on campus and that operate on a combination of steam and electricity may be helpful. Many houses have simple HVAC systems. In winter, a gas- or oil-fired furnace supplies heat to an air circulation system in which a fan pushes heat and air around the house; that is heat and ventilation. In summer, an electrical refrigeration unit chills and dries the air, and the same fan system distributes it around the house; that is ventilation and air conditioning. Even in seasons when neither heat nor cooling is needed, one can run the fan for ventilation only.

But campus HVAC systems are more complicated. They often consist of several different components, some of which are not always located in the building they serve. For example, large boilers are sometimes located in central power plants from which hot water or steam is piped to the individual buildings. Within the buildings a variety of systems are used to heat, cool, and ventilate the space. Four of the more common systems are examined here: terminal reheat, dual duct, induction, and radiator.

Terminal Reheat System

The terminal reheat system illustrated in figure 2.9 has been simplified to show just two rooms. The supply fan is driven by electricity, and pulls air over the cooling coil, reducing its temperature to 55°F, and pushes it into room 1 through a reheat coil heated with steam. The cooling coil operates on chilled water. Since the 55°F air may be too cold for room 1, a thermostat activates the reheat coil, which then heats the cool air to the proper temperature. Thus, this system uses energy to cool the air, then uses additional energy to reheat it.

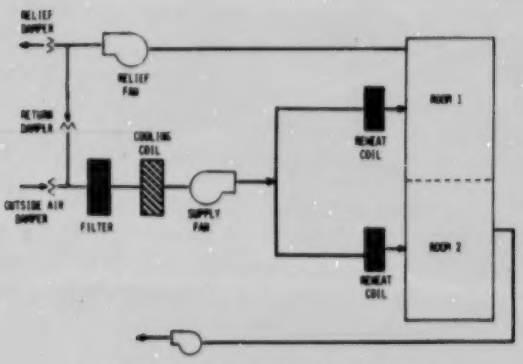


Figure 2.9. Terminal Reheat System

But room 2 may require a cooler environment than room 1. This can be accomplished by running the main cooling coil at a low enough temperature to satisfy the needs of room 2, and by room 1 taking steam through its steam coil to overcome the chill it does not need. It would not be good advice to tell the occupants of rooms 1 and 2 to turn their thermostats up during the cooling season, because any call for less chill is accomplished by reheating air that has already been chilled, thus using more total energy.

Waste in the terminal reheat system occurs because of the simultaneous presence of cooling coils and heating coils in the system. This type of system was designed in an era when energy was one-third or one-quarter of its 1976 price. However, if precise control of temperature is required, there is no better system than one that cools all air just a little beyond that which is needed, and then trims it back with a reheat coil to precisely the target temperature. Such a method of simultaneous heating and cooling is employed in a shower, since there are two sources of water: one hot at about 140°F and one cold at mains temperature (40–60°F). In the shower the two faucets are adjusted until a comfortable temperature is reached; hot water is mixed with cold water to make a tepid shower at about 100°F.

In the cooling mode of the terminal reheat system, the analogous situation exists. All the air is cooled to 55°F. Only a little of the air needs to be 55°F (say, that which goes to room 2), so all the air that goes to room 1 gets reheated to 60–65°F so that it does not overchill room 1. Three times more energy is used to chill the air than to temper the chill, whereas all that really is needed is perhaps enough energy to chill the air mildly for room 1.

Every time the cooling coil and the reheat coil "balance" each other, extra energy is being used solely in the interest of precise temperature control, which may or may not be needed in all rooms. In chapter 4 it will be noted that by making a small sacrifice in precision control, alterations to this system can be made that will eliminate much of the heat-cool-reheat-recool program, which is wasteful. The skill in modifying the system lies in minimizing the "balancing," while still retaining an element of temperature precision in those rooms that need it, such as biological science labs that depend on precise environmental control for the success of experiments.

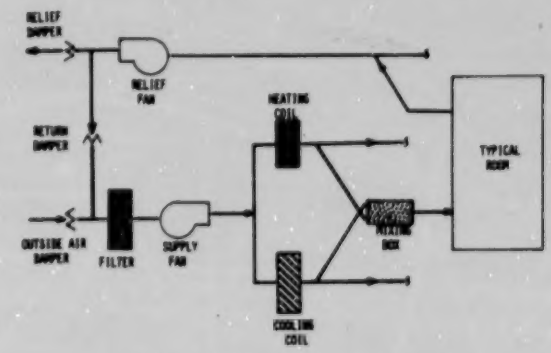


Figure 2.10. Dual Duct System

Dual Duct System

Figure 2.10 illustrates a dual duct system. In this system the supply fan draws a mixture of outside air and recirculated air through a filter but not through a cooling coil. To the right of the supply fan the duct splits immediately into

two parallel lines (dual ducts), with one containing the cooling coil and the other the heating coil. Every room is ducted to receive both streams, brought into the room via a mixing box. Within the mixing box is a vane, which can be positioned by a thermostat to give more hot air and less cold air, or vice versa. The volume of air is set by design so that on the hottest day, and with chilled air at 55°F, the room will attain its designed comfort with the flow provided, with the vane over to maximum cool air.

During the heating season, there are certain rooms on the perimeter of the building that, because of their proximity to an outer wall, are equipped with hot-water baseboard heating as well as the duct system. Since these rooms have their own auxiliary heating system, they are unlikely to ever need the full blast of hot air that comes through the duct. However, because there is no way to reduce this flow for individual rooms, the excess heat is eliminated by mixing in cold air from the cold duct.

In this system, multiple waste of energy may occur. For example, on cool days such as in spring and fall, the air brought in from the outside needs little conditioning, yet this system arbitrarily heats a portion of the air, then cools another portion, and then mixes both together, resulting in waste of energy. Similarly, on hot, humid days, this system continues to take an arbitrary volume of outside air. If that volume is not needed for health reasons, energy waste occurs, since the outside air that is introduced must now be cooled.

Chapter 4 contains specific energy-saving measures that can be applied to these systems to minimize waste. Savings of from 40% to 60% are possible without causing major upset to those portions of a building that do not require very precise temperature control.

Induction System

Figure 2.11 shows an induction system; in this system, a fan is driven by electricity, cooling coils operate on chilled water, and reheat coils operate on steam. The principal difference between this type of system and the dual duct and terminal reheat systems is the way in which return air is handled. Instead of being brought back from the rooms to the fan, the return air takes a shorter path. Every room receives a jet of fresh air from the outside into which is mixed a portion of the room air. The mixing is accomplished with a nozzle, which is similar to a carburetor, except that a carburetor mixes air with gasoline. This nozzle mixes fresh air (suitably cooled or heated) with room air. There is a constant blast of air into the room. If the room gets too hot in winter, a cooling coil just outside the room decreases the temperature. If the room gets too cool in summer, the same coil operated with steam takes some of the chill out of the fresh-air jet.

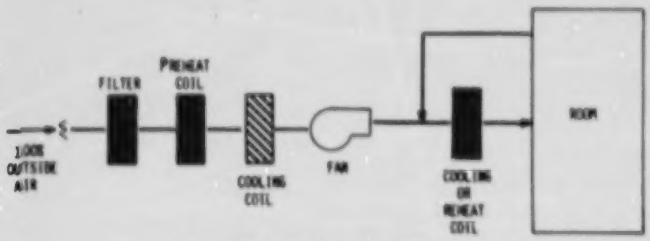


Figure 2.11. Induction System

Like the other two systems, the induction system calls for the balancing of heating and cooling coils utilizing full flow volumes, which again may be more than is required for health reasons. It should be noted that all the air injected into the system is outside air, which is acceptable during seasons in which the outside air has already been "conditioned" by nature; but it is questionable if this is the optimum way in which to operate when the outside air is hot and humid in summer or cold and dry in winter.

Radiator System

A simpler heating system, found particularly in older buildings, is the well-known radiator, which is usually heated by steam, but sometimes by hot water.

A steam radiator has an inlet for the steam

and an outlet for the condensate. As mentioned earlier, condensate is the name for water that condenses in steam systems, and the way in which the condensate is treated affects system efficiency. A steam radiator also has a small air vent to bleed air out of the system. In a hot water radiator, hot water enters the radiator, and cooler water flows from the outlet. There is no fan power required with radiators since they rely on natural convection to carry the heat around the room in a gentle air current generated by the heat itself. In a typical hot water radiator system, electricity is required to pump the water from the boiler through the radiators and back to the boiler.

Obviously, radiators are not employed to cool premises in summer, since they would be very inefficient if used that way. Facilities using radiators for winter heat have a separate summer air conditioning system, or individual room air conditioners, or nothing at all. Ventilation of such buildings is performed by opening and closing windows.

In comparison with the complicated systems described earlier, radiators are very efficient, even though they lack the precise control capability that may be needed in science and medical buildings. However, energy waste can still occur (1) with "self-balancing acts"—for example, the opening of windows in winter to compensate for an overabundance of heat from radiators, or (2) within the steam system itself, as in the case of the disposition of the condensate that comes from the steam trap.

Ventilation

Another form of campus energy use and waste is related to the degree to which a building is ventilated. Specific amounts of air flow are needed within a facility for health purposes, depending on the type of activity taking place. For example, if people are cooking, there is a need for faster air change than if the people are typing. Similarly, if chemistry experiments are being conducted, there is need for a faster air change than would be required for a lecture. Generally speaking, ventilation systems such as the terminal reheat and dual duct systems are designed to provide more air than required to meet standards for health and comfort.

Accordingly, if air flow exceeds the minimum required for health and comfort standards, three types of energy waste can result:

1. Since excess amounts of air are being brought into the building and then exhausted, more fan power than necessary is being used to move the excess air.
2. Similarly, more steam or chilled water is needed to condition this excess air in proportion to the volume flowing. To the extent that the volume flow can be reduced, the energy for its temperature control is cut down nearly in proportion.
3. Part of the function of summer air conditioning is to reduce the humidity of the air at the same time air temperature is being reduced. About one-third of the energy in an air conditioning system is used to dry the air and about two-thirds to cool it. Thus, if a larger-than-necessary volume of air is being used in the system, a larger-than-necessary energy load for drying the air is also being used.

Changes in ventilation rates (air flows) can usually be made relatively easily and inexpensively, and most importantly, significant amounts of energy will be saved. However, it is important to re-emphasize that the nature of the activity within a building, its occupancy level, and local codes must be carefully reviewed prior to making such changes.

Unoccupied Spaces

All HVAC systems share the potential for another type of waste—the waste inherent when service is supplied to unoccupied spaces, such as vacant offices and laboratories, or to areas not used at night or over weekends and holidays. If spaces are unoccupied, elimination or reduction of the heating or cooling supplied to the space will yield significant savings of energy.

The various systems described earlier may have been designed without any means for cutting off service to discrete parts of a building. Such systems may also be so complicated that it is difficult and costly to curtail service in off-hours as long as even one small part of the building (a specialized lab, for instance) requires continued service. However, in chapter 4, some methods for modifying the systems in order to allow them to work on a partial load and on a part-time basis will be examined.

Energy Data Base

An effective energy management program depends on current, accurate data. Such data are critical in order (1) to determine priorities for action, (2) to monitor and evaluate the success of a program as it proceeds, that is, to prove that energy consumption reductions have been obtained and to know where they have been achieved, and (3) to discuss energy management problems and opportunities with consultants and others.

To effectively monitor energy use and consumption reduction, data are needed on primary energy use, conversion efficiencies, distribution losses, and energy end use. Some of these data will be relatively easy to obtain, while others will be more difficult. As data collection progresses, an appreciation of its usefulness in assessing problems, establishing priorities, and tracking performance will quickly develop. Ultimately, metering individual buildings or individual systems may be worthwhile for thoroughly refining a data system. However, before reaching this point, an overall view of the efficiency of energy use is required.

Primary Energy Data

Prior to mounting any type of energy management program, it is essential to know the quantity and cost of energy being purchased. It is also important at an early stage to determine the most economical fuel that can be used and the optimum available fuel mixes. Appendix A-2 contains a form on which price and consumption data may be tabulated monthly; such a tabulation is just a start, but an important one. With no other data at all, some useful comparisons can be made with other institutions, and the rate of growth of institutional energy use can be monitored. The form mentioned above, a portion of which is shown here as figure 3.1, contains 42 columns, covering some sample weather data (columns 2 and 3) and all the fuels likely to be purchased.

Heating degree days (column 2 on the form) may be useful in explaining how consumption of various fuels is affected by cold weather. A case history is given in appendix A-4, in which a graphical technique is used to determine a base load and a cold weather dependent load. Degree days are a simple way of explaining some of the short-term fluctuations in the consumption of fuel; they are not accurate for analyzing or explaining fuel usage over the longer term. Such variables as building skin, building use, building age, wind chill, and hours of sunlight challenge the accuracy of any energy analysis based solely on degree days. Nevertheless, weather indexes are helpful in explaining certain consumption variations and thus are worth consideration in the total context of an energy management plan.

In the straightforward cases of oil, coal, and perhaps "other fuel" such as sawdust, there are three columns each on the form. For heavy oil, these are:

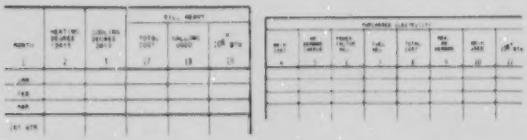
1. Total cost for the month in dollars.
2. Quantity in customary units (gallons, tons).
3. Heat content in millions of Btu's.

Conversion factors are also given on the form to establish the Btu content for all fuels and energy forms except coal and "other fuels." If coal or "other fuels" are purchased, it will be necessary to obtain conversion factors from the supplier or from an analysis of the fuel. However, in round figures, coal usually con-

tains 25 million Btu's per short ton, and sawdust, 16 million Btu's per short ton.

The form also provides columns for recording data beyond the basic cost and consumption items. Under the headings "Purchased Electricity," "Purchased Steam," and "Gas," it is important to note that there is an additional space on the form for the demand factor. Using electricity as an example, utility charges are primarily based on two data items, those from columns 4 and 5 in figure 3.2: How much electricity in kWh is actually consumed in the month (use factor)? And what is the highest short-term level of demand in kW during the month (demand factor)?

In the case of steam, the use factor would be the pounds of steam used in the month, and the demand factor would be the highest recorded flow of steam in pounds per hour. In the case of gas, the use factor would be the total cubic feet used in the month, and the demand factor the highest flow of gas in cubic feet per hour.



Figures 3.1 and 3.2. Energy Survey Form

The reason for these demand charges is that the supplier must be compensated for holding equipment in readiness to supply a peak demand. Looked at from the consumer's point of view, anything that will reduce peak demands will reduce the electric bill, even if the same number of kilowatt hours are used.

In the electricity columns (4 to 11), column 8 is the total cost of electricity, column 9 the peak kW demand, column 10 the total kWh's used, and column 11 the total Btu's, which is a figure based on kWh's, i.e., the figure recorded in column 10 multiplied by the factor 0.003412.

In the particular case of electricity, there may be one or two extra charges; these are power factor charge (column 6) and fuel adjustment charge (column 7). Space has been left on the form for their inclusion so that a monthly comparison can be made of the electric bill components.

Conversion Efficiency Data

Several energy conversions are made on campus, and, as noted earlier, such conversions can differ markedly in relative efficiency:

1. Boilers convert primary fuel to steam.
2. Steam may be converted to chilled water by absorption, or by steam-driven centrifugal compressors.
3. Electricity may be converted to chilled water by compressors.

Here again, it is important to be aware of these conversions and to keep accurate records of such efficiencies.

The various efficiencies to be expected from a boiler, based on the fuel used, have been discussed. Appendix A-3 is a case history on improvements that can be made to boiler systems.

Data on cooling equipment efficiency can be obtained by reading the nameplate on the equipment. For example, a 50-ton centrifugal unit may be described as consuming 50 horsepower or perhaps 60 kW. If a catalog of such data is kept, it will be easier to determine how much energy is flowing through the equipment, and to decide whether or not the system is operating efficiently.

Distribution Data

Energy is lost in both electrical and steam distribution networks. In the former, there is little that can be done except to keep close watch on the power factor, a subject to be covered in chapter 5.

In steam systems, losses are usually associated with condensation in the outgoing line, and with condensate returning to the boiler. In order to judge the seriousness of such losses, the principal data needed are: (1) the amount of steam in pounds per hour leaving the boiler (this is practically always available from the boiler instruments) and (2) the amount of condensate return in pounds per hour and the temperature of this condensate (this is probably best judged by subtracting the amount of make-up water used from the steam output). Ideally, almost a full pound of condensate would return for every pound of steam going out, and that condensate would be at a high temperature. In practice, the condensate re-

turn is always less than 100%, and it is usually cooler. However, with actual figures, it is possible to calculate exactly how much energy is being lost in the steam distribution system, and subject to such variables as distance, pressures, and the cost of make-up water, it may or may not be economical to recover this energy. This determination can be made only if accurate data are available.

End Use Data

The initial need to record overall consumption and cost of energy month by month has been mentioned. The next step in assessing the efficiency of energy end use is to compile a record of the total square feet of building space in the institution. Such a step permits an analysis of energy use in terms of so many kWh's/square foot annually, and so many Btu's/square foot annually for the institution as a whole.

The amount of energy used per square foot varies with the type of facility in which the energy is used and with the type of activity that takes place in the facility. Table 3.1 provides an example of the difference in consumption by activity.

TABLE 3.1
Energy Consumption per Square Foot per Year

	Thousands of Btu's	Electricity kWh's
Dormitories	115	6
Academic	140	15
Student Activity	210	15
Science	400	30

Since energy use differs among facilities, a logical next step in analyzing energy end use could be the listing of buildings by functional category, i.e., science, academic, gyms, etc. This step will permit the identification of square feet contained by these functional categories so that energy consumption by type of building may be examined. A specific case from M.I.T. is presented in figure 3.3, where the energy requirements of the functional categories are juxtaposed to the square footage of the functional classes.

In this case, it is apparent that the science facilities require about the same amount of total energy as the dormitories, in spite of the fact that the science facilities represent only one-third of the building area of the dormitories. From such a functional breakdown, it becomes clear that the science buildings, with their sophisticated HVAC systems, are very energy-intensive per square foot when compared with other classes of campus facilities. Clearly, there is an incentive to thoroughly investigate the consumption reduction potential of these buildings, since high energy consumption and thus cost per square foot can yield energy and cost savings, especially where HVAC modifications are involved.

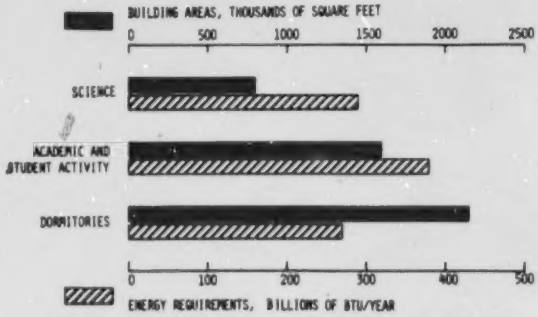


Figure 3.3. Energy Requirements for Different Buildings

This is not to say that other facilities should be ignored or that low-cost, quick-fix measures, such as those discussed in chapter 4, should not be implemented. Rather, it is this type of energy/square foot/functional class analysis that can help to identify heavy energy users and thereby establish energy management priorities.

In summary, the first three steps in the accumulation of end use data are:

1. Assemble gross energy consumption and cost figures.
2. List gross square feet of total building space on the campus.
3. Identify the square footage by functional classes of buildings and examine energy consumption of these classes.

One additional step, where feasible, will be extremely helpful in analyzing the efficiency of campus energy use:

4. Determine the energy consumption of each building, and if it has multiple systems, the energy consumption of each individual system.

As in the functional classification of facilities, a building-by-building analysis will assist in the

further identification of conservation problems and potential, and will be helpful in devising measures for reducing energy consumption. The ability to undertake an accurate building-by-building, system-by-system, or, in some cases, functional classification analysis will most likely depend on a system of metering. The figures given earlier for kWh's and Btu's per square foot of building category were obtained from institutions with metering capability. It is important to note, however, that lack of metering capability should not be considered an obstacle to effective data gathering and analysis. Even if an institution can assemble only cost, consumption, and square footage information, a good start will have been made on the data system.

Consultants

To explore energy management problems and opportunities, it is necessary to have data on which to base decisions. Many of the larger institutions may have the in-house capability to analyze energy data. However, physical plant engineers, schools of engineering, and other resources in the larger institutions may not be available to smaller institutions. In such cases it may be necessary to use consultants who specialize in energy problems. Even some of the larger institutions often bring in outside assistance when confronting the variety of options and opportunities associated with effective energy management.

Before retaining outside consultants, it is important to inquire about their reputations, and to know their fields of expertise. It may be advisable to hire a consultant on a small project for the first time; this will provide an opportunity to evaluate performance before committing to a larger project. Consultants will be able to assist in the identification of investments that will yield the most favorable returns, and will be able to provide guidance in their implementation. However, any new project requires careful study; any evaluation must relate to the context of the specific situation.

In conclusion, potential energy wastes should be studied, potential modifications should be understood, accurate information should be kept, and assistance should be sought, if needed.

Evolutionary Approach to Energy Conservation

Energy management is an evolutionary process. Institutions that have operated the most successful energy waste elimination and cost reduction programs have done so by following a carefully planned and coordinated program, moving from the most elementary conservation steps to levels of increasing sophistication. Any successful program must be based on initiation of the most obvious conservation steps—those that may require little capital investment but perhaps great effort in retraining people and reshaping attitudes. An energy management program cannot afford to outpace the capabilities of the people who are responsible for, and involved in, its implementation.

The purpose of this chapter is to examine a variety of energy management measures, based on the experience of a diverse group of colleges and universities. While only a few ideas are discussed, there are many other measures that can be applied, most of which may be found in appendix B; it should be noted that these measures are not listed in any order of priority. Application of some, or all, of the ideas will result in significant reductions in energy consumption, thereby saving fuel and financial resources.

From the point of view of energy use, a building or complex of buildings may be regarded as a system comprised of three parts:

1. Energized—mechanical systems, boilers, chillers.
2. Nonenergized—walls, building envelopes, controls.
3. Human—operation and maintenance.

Each of these parts can be modified to yield energy savings.

Because the energized component of the system is typically the mechanical equipment that uses energy directly (HVAC systems), it is logical to target this equipment for energy modification. To make HVAC systems the only targets would be a mistake, however, since modification of this equipment depends on many factors. Accordingly, effective energy management requires knowledge of relationships within the entire system and the effects of these relationships on building users.

In order to better understand the phases, or the multistep approach to effective energy management, it is useful to separate energy modifications into three categories, based on consumption reduction and payback. These categories are: (1) quick fix, (2) refit, and (3) systems convert.

TABLE 4.1
Savings and Payback

	Energy savings	Payback period
Quick fix	10%–20%	Up to 6 months
Refit	10%–15%	6 months to 3 years
Systems convert	10%–?	2 years to 5 years
Accumulated	30%–45%+	

As noted in table 4.1, each category of modification offers a greater opportunity for consumption reduction than that preceding it, and each involves an increasing rate of capital expenditure.

Quick fix modifications can be defined as energy consumption reduction measures that achieve rapid and significant energy savings at negligible cost, or at a cost that can produce a return on investment in no more than six months. These modifications can normally be

accomplished by operating and maintenance personnel. Conservation measures such as the adjustment of temperatures and lighting levels will quickly eliminate obvious waste, resulting in energy reductions of at least 10% for most institutions. Minimal preparation is required for implementing these quick fix measures, especially with campus-wide cooperation. It should be noted that quick fix is never fully accomplished; there are always some overlooked opportunities.

Refit modifications can be defined as energy consumption reduction measures that require modest capital investment, but can yield an additional 10% to 15% in energy savings, with payback in a period of six months to three years. Prior to committing capital for refit measures, each campus should analyze its own needs and decide which modifications will be most cost-effective.

Systems convert modifications can be defined as energy consumption reduction measures that are the most sophisticated and expensive, generally involving major changes in systems design. Systems convert measures will generally yield at least an additional 10% savings in energy and will involve paybacks of from two to five years. Institutions that specialize in scientific and medical research or other energy-intensive activities generally will benefit most from systems convert measures. Normally, such measures would be implemented after thorough quick fix and refit programs have been initiated.

Since a key consideration in any energy management program is the establishment of priorities, that is, which measures should be implemented first, it is important to examine and set priorities in a methodical and evolutionary fashion. Thus, initial measures will be concentrated on low cost, fast-payback, quick fix measures leading up to refit and systems convert modifications. This relative sequence does not infer that all quick fix measures must be implemented prior to turning to refit or that all refit measures must be implemented prior to turning to systems convert. Just as an energy management program must be evolutionary, it must also be simultaneous. For example, three years after a conservation program has begun and work on systems convert options may be under way, certain quick fix measures will still be ongoing. Temperatures will be kept down in the heating season, lights continually removed, and preventive maintenance (a key quick fix item) continued.

Establishing an appropriate priority sequence for an energy management program depends on the variety of physical and social factors that characterize each institution. In all cases, however, it is important to concentrate on measures that will yield demonstrable energy savings and a rapid return on invested capital.

One university has used its experience to compile a list of typical modifications to be implemented in facilities that are not energy-efficient, that is, where little or nothing has been done. In table 4.2, it should be recognized that savings shown are not additive. In other words, if modification A will save 10% and modification B, which involves the same system, can save 10%, implementation of both measures may result in a savings of 15% rather than 20%.

TABLE 4.2
Savings and Payback

Action	Energy savings	Payback
Unoccupied shutdown and temperature setback	10% to 30%	
Elimination of simultaneous heating and cooling on dual duct, reheat, and induction systems	10% to 20%	
Calibration and proper operation of temperature controls, including dampers and damper operators	5% to 15%	
Reduction of lighting levels and air quantities	5% to 10%	
Centralized control systems	5% to 20%	2½ to 6 years
Envelope improvement, better insulation and glazing		5 to 15 years
Heat reclamation		5 to 20 years
Solar applications		10 to 20 years

Quick Fix

Some of the more effective quick fix measures that have been implemented at colleges and universities are:

1. Reduction of lighting.
2. Unoccupied shutdowns and temperature setbacks.
3. Use of warm-up cycles.
4. Reduced ventilation rates.
5. Resetting mixed temperature (terminal reheat system).
6. Resetting deck temperatures (dual duct system).
7. Increase in chilled water temperature to air handling units.

Typically, these measures involve little or no capital expense, and thus can be implemented immediately.

Reduction of Lighting

One of the most visible wastes of energy on the campus is lighting. Excess lighting results in energy waste, since energy is used both for lighting and also for the cooling that is often necessary to offset the heat created by the lights. Several different steps can be taken to reduce the energy consumed by lighting systems:

1. Establish illumination levels.
2. Establish usage program.
3. Remove unnecessary lamps.
4. Use more efficient lamps.
5. Improve maintenance.

In all cases, however, it should be recognized that lighting serves a variety of purposes. Accordingly, while reduction of lighting is possible, it is important to consider and evaluate the use of certain types of illumination and to make certain that safety and security are not jeopardized.

Establishment of Illumination Levels. One of the first measures to be implemented in an effort to reduce lighting levels is a lighting survey, to determine what quantity and quality of lighting are used and when lighting is used. Such a survey may point out that the lighting system design and controls are completely adequate for building use during normal occupancy periods. However, if a building is occupied by a few persons after normal occupancy periods, as is often the case in buildings that house computers and related data processing equipment, significant waste may occur because controls do not permit the necessary selectivity during off-hours. Therefore, all data on lighting systems and building use must be on hand so that decisions regarding lighting system modifications can be made in an informed manner.

In most buildings there are three general categories of illumination required: specific task lighting, general lighting around tasks, and general lighting for circulation and support areas. Existing lighting levels in standard foot-candles can be determined with portable illumination meters (a foot-candle is the illumination of a surface one foot distant from a source of one candela, or standard candle, equal to one lumen per square foot). Generally, measurements refer to average maintained horizontal foot-candles at the task or in a horizontal plane 30 inches above the floor. The Federal Energy Administration (FEA) has developed lighting standards that are generally accepted (table 4.3).

Establishment of a Usage Program. A lighting usage program should be established to schedule lighting use with building occupancy patterns. Accordingly, surveys should be conducted to determine the amount of lighting needed for task performance, safety, and security in a given space for specific periods of time, such as occupied hours, evening hours, weekend/holiday hours, etc. Such a lighting schedule is especially important for periods when a building or space is occupied by maintenance and/or custodial personnel, since in many cases, lights on an entire floor will remain on while custodians move from area to area. However, by developing a schedule and assigning lighting control responsibility, where feasible, it is relatively easy to insure that such energy waste is reduced, if not eliminated altogether. The lighting usage program may be made even more successful when some of the following measures are employed.

Switch identification, such as small labels or signs that identify specific lamps controlled by the switch, makes it easier to identify and turn out unneeded lights.

A campaign for more effective use of lighting can also be mounted. Through such mechanisms as personal contact, memoranda, and

TABLE 4.3
FEA Recommended Maximum Lighting Levels

Task or area	Foot-candle levels	How measured
Hallways or corridors	10 ± 5	Measured average, minimum 1 foot-candle
Work and circulation areas surrounding work stations	30 ± 5	Measured average
Normal office work, such as reading and writing (on task only), store shelves, and general display areas	50 ± 10	Measured at work station
Prolonged office work that is somewhat difficult visually (on task only)	75 ± 15	Measured at work station
Prolonged office work that is visually difficult and critical in nature (on task only)	100 ± 20	Measured at work station
Industrial tasks	ANSI-A11.1-1973	As maximum

signs that encourage occupants to use only the illumination required and to turn out lights whenever they are not needed, further savings can be achieved. In many cases preprinted labels can be affixed to light switches, encouraging occupants to turn them off after use. (See chapter 7 for point-of-use materials.)

Timers on light circuits have been installed by many institutions so that lights are automatically shut off after a certain period. This type of control insures that lights are on only when needed, while also keeping persons responsible for turning lights on aware that lights are being automatically shut off to conserve energy.

Removal of Unnecessary Lamps. When removing fluorescent or high-intensity discharge lamps, it is important to remember to remove the ballast also (or disconnect it in place). If the ballast is left connected to the power source, it will continue to consume energy even though it serves no purpose. When two-lamp fluorescent fixtures are mounted in a row, the lamps should be removed in alternate fixtures of the rows. However, in order to maintain the recommended lighting level, it may be necessary to use increased output lamps in place of some of the remaining lamps. Even so, this should result in net savings of energy.

Use of More Efficient Lamps. Efficiencies vary among lamps consuming the same number of watts and among lamps of the same type. As shown in figure 4.1, efficiencies range from less than 23 lumens per watt to more than 180 lumens per watt. Most manufacturers have developed lamps designed specifically for refitting existing fixtures. For example, reduced wattage fluorescent lamps that operate on standard CBM ballasts are available. These lamps use less energy, provide more lumens per watt, are interchangeable with other lamps, provide the user with a choice of wattage, and maintain light distribution and lighted appearance.

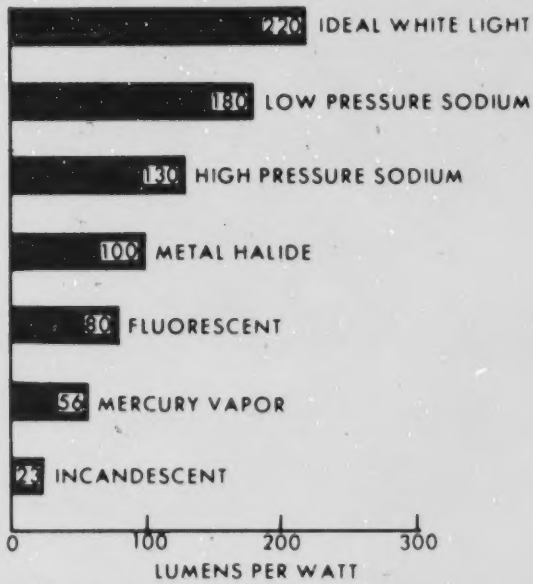


Figure 4.1. Relative Efficiency of Lamp Sources

Combined with low-energy ballasts, such lamps provide even greater savings. (It should be noted that starting problems have been experienced in some low-energy ballasts at temperatures of 68°F and below.) With either

type of ballast, however, light levels in overlighted areas can be uniformly reduced without relocation of fixtures.

In addition to the fluorescent tubes mentioned above, a "phantom tube" is also available. This tube, which produces no light, looks like a standard tube, but contains a small capacitor that maintains the electrical balance in the circuit. Tests have shown that pairing a fluorescent tube with a phantom tube gives the former a life as much as 80% greater than normal, and the life of a phantom tube is many times greater than the 20,000-hour utilization expectancy of the standard 48-inch tube.

Improvement in Maintenance. With adjusted (lower) lighting levels, proper maintenance of lamps becomes critically important, since it is necessary to make certain that all available light is being captured. Accordingly, certain maintenance measures are mentioned below:

1. Lamp efficiency deteriorates over the life of a lamp, so light output should be checked regularly with a calibrated light meter. A rule of thumb is that when the output of a group of lamps falls to approximately 70% of original ouput, all fixtures in the group should be relamped and cleaned at the same time.
2. Lamps should be wiped clean at regular intervals to insure maximum efficiency. When exposed to an atmosphere with substantial dirt, dust, grease, or other contaminants, lamps should be cleaned more frequently than when they are in a relatively clean atmosphere.
3. Lamp efficiency can be maintained by properly cleaning reflecting surfaces and shielding media. Lenses that have yellowed or become hazy should be replaced.
4. Ceilings, walls, and floors should also be cleaned frequently to improve reflective qualities. When daylight is used as a light source, windows should be washed frequently.

Use of Timing Devices and Thermostats for Unoccupied Shutdowns and Temperature Setbacks

Substantial energy savings at relatively low cost can be achieved by using timers and thermostat controls in order to "shut down" or "set back" a building during unoccupied cycles. (Experience has shown that only a small portion of a building actually requires 24-hour or night operation.) Mechanical systems that formerly ran 24 hours a day, seven days a week, can be effectively regulated so that heating and cooling are provided only when needed, thereby eliminating significant amounts of energy waste. Accordingly, a survey of building occupancy patterns should be undertaken so that shutdown or setback potential is revealed and so that the most beneficial type of modification may be determined. One of the most useful timing/thermostatic controls employed by colleges and universities for their heating systems is the low-limit night thermostat connected to a timer.

Such a thermostat is controlled by a time clock that, at a preselected hour, starts and stops selected fan units and/or opens or closes automatic water or steam valves to maintain a desired temperature. It should be noted that separate convector or radiation hot water systems in buildings normally can provide adequate heat during unoccupied periods without operating large central supply air systems. These radiation systems can often be automatically shut off at temperatures of 35° to 45°F and above, depending on the building envelope involved, the amount of glass, wall construction, etc. When an HVAC system is de-energized during unoccupied periods, it is essential to keep outside air dampers closed tightly. Dampers on exhaust fans that interlock with outside air fans should also be checked to be sure they close properly.

Although these types of shutdowns during unoccupied hours seem an easy and obvious step, they typically were not used before energy became a problem. As a result, the savings to be obtained are substantial. One university reduced its gas and electric bill by about 28% for an annual savings of about $34,000 in just one building, an agricultural facility with no laboratories. This university programmed its start-up and shut-down in accordance with the needs and typical occupancy patterns of the various buildings involved; the programmed schedule was followed through either manual or automatic activation of controls. It is worth noting that the schedule called for sequencing start-up of HVAC equipment to minimize electrical demand.

In some cases refitting of a system will be

required to gain the type of control that allows programming for an unoccupied period. That is, it may be necessary to spend money to install unitary equipment that will allow deactivation of a major system. However, such refit modifications will generally lead to fast paybacks.

Addition of a Warm-up or Cool-down Cycle

With air handling units that employ outside air intake, it is advisable to incorporate a warm-up or cool-down cycle into the system. A diagram of a typical warm-up cycle is shown in figure 4.2. The purpose of the cycle is to keep the outside air dampers closed during morning warm-up or cool-down. Only heating and cooling of the air already in the building would then be required, eliminating the need to treat air that would normally be brought in through the open ventilation system. In the schematic, a two-circuit time clock controls the outside air damper and fan operation.

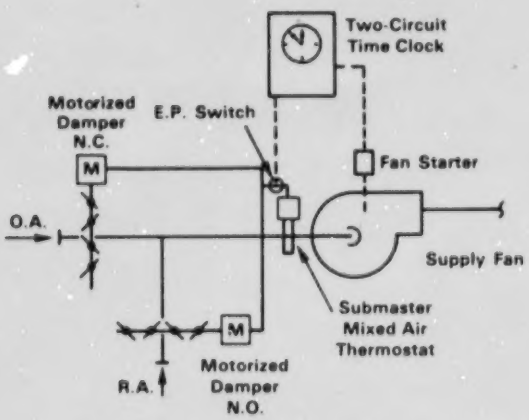


Figure 4.2. Typical Warm-up Cycle

Reduction of Ventilation Rates During Occupied Periods

The amount of outdoor air introduced into a building for ventilation by mechanical systems is perhaps the single most important factor that influences a building's heating load in winter and its cooling load in summer. Such air must be either heated or cooled and then humidified or dehumidified to meet indoor requirements. However, many buildings are ventilated at a rate far in excess of that necessary to maintain comfort, to dilute odors, and to meet code requirements. Significant savings can thus be attained by adjusting ventilation rates.

Three considerations prior to adjusting ventilation rates are:

1. Determine current ventilation rates by measuring the volume of air at the outdoor air intakes of the ventilation system.
2. Determine typical occupancy patterns for the building involved. (During what days of the week and what hours of the day is peak occupancy reached, and how many persons are involved?)
3. Determine fresh air code requirements for the facility involved.

Reduction of ventilation rates to the minimum possible, usually about five cubic feet/minute/person, is desirable. Most buildings have ventilation rates in excess of code requirements even though it is generally recognized that codes themselves call for more ventilation than required. Thus, it should be determined whether ventilation rates meet code specifications. Ventilation rates may be measured by using an anemometer at the outdoor inlet or louver to measure the amount of outdoor air introduced into the ventilation system. It is well to remember that the outdoor air damper setting often differs from the damper indicator setting and that a hinged volume damper blade does not proportion air directly with its opening; a blade with a 10% opening permits much more than 10% flow.

In many cases reductions in ventilation rates can be achieved without violating codes simply by closing outdoor air dampers until the desired volume of air is flowing. Thus, it is important to make sure dampers are in proper working order and correctly adjusted in order to capitalize on this inexpensive yet significant energy-saving method. Similarly, thought should also be given to ventilation system "cycling," that is, turning off a system for 15 to 20 minutes out of each hour; in this way, the building "coasts" on its existing air. However, this practice must be used with caution where certain research activities are involved. One northern university estimates that 1,000 cubic feet of air/minute costs $500 a year.

Reduction of Exhaust Hood Use

More important than the *direct* energy used by exhaust hoods in kitchens, laboratories, and

medical and research buildings is the *indirect* energy consumption of this equipment. Every cubic foot of air exhausted must be replaced or "made up" by outside air which, in turn, must be conditioned: heated, cooled, and humidified or dehumidified by mechanical systems.

As shown in figure 4.3, a typical fume hood requires energy for make-up air equivalent to that required to heat one four-bedroom house or to cool two four-bedroom houses annually. The most obvious method for cutting back the energy required for make-up air is to reduce hood use to a minimum. A schedule for hood use will thus be helpful, since it is necessary to know how and when hoods are being used, and when and where they may be turned off.

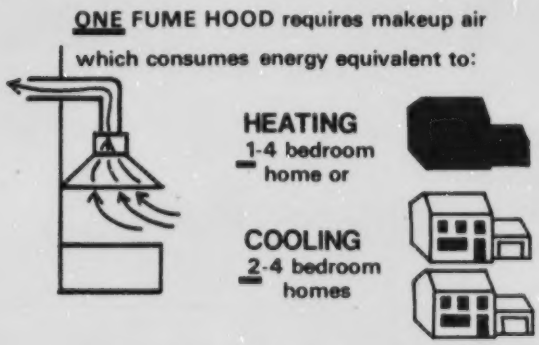


Figure 4.3. Make-up Air for Fume Hoods

Minimizing the Heating and Cooling of Air

One of the simplest techniques for achieving energy savings involves minimization of the heating and cooling of air by adjusting thermostats and related controls. Winter-season settings shown to be most effective in terms of energy and comfort are listed in table 4.4.

A temperature of about 80° is generally accepted for summer settings except in certain research, infirmary, or other special areas. The settings selected should not result in energy waste. For example, in certain systems such as dual duct, a lowering of the thermostat to 68° could cause activation of the cooling system. That is, heated air in such a system may have to be further cooled to reach this lower temperature.

TABLE 4.4
Suggested Winter Settings

	Dry Bulb °F Occupied Hours	Dry Bulb °F Unoccupied Hours
General recreation areas	60°	60°
Office and general purpose academic space	65°	60°
Infirmary, patient area	72° to 76°	72° to 76°
Storage	55°	55°
Animal care and special research	As required	As required

Infiltration and Heat Loss

Just as heat enters a building during the summer, it escapes or leaks out during the winter. Because of the slight pressure developed by a ventilation system, some heat leakage occurs around windows, doors, skylights, and shipping and receiving rooms. These heat losses, along with wall conduction heat losses, cause the efficiency of the heating or cooling system to decrease. Total amount of heat loss depends on operating procedures as well as on the physical condition and characteristics of the building.

A few specific steps that can be taken to reduce heat loss and infiltration are listed below (see appendix B for a complete list).

1. Inspect building exterior and interior surfaces. Caulk all cracks, where possible.
2. Caulk around all pipes, louvers, or other openings that penetrate the building skin.
3. Repair windows.
4. Weatherstrip exterior doors and windows.
5. Cover window air conditioners.

Resetting Mixed Air Temperature in Terminal Reheat Systems

Terminal reheat systems are popular because they allow a high degree of temperature and humidity control; but as shown in figure 4.4, they waste energy. In this system, supply air is passed through cooling coils that reduce the air temperature to approximately 55°, and then the cooled air flows through ducts to each of the spaces served. However, prior to entering the space, the cooled air passes through a terminal heating coil, a device that heats the air to achieve the thermostatic setting in the space involved. It is quickly seen, therefore, that energy is being expended first to cool and then to heat the air.

A technique used by several colleges and universities to minimize the energy consumption of terminal reheat systems is worthy of

note and implementation: In the summer season, the reheat coils were kept off and the air temperature leaving the cooling coil was adjusted manually so that air was circulated at a temperature from 60° to 70°, depending on building characteristics and the heat generated by its occupants. In one full summer of operation on this pattern, it was found that temperature and humidity levels in most spaces were completely satisfactory. The result was a reduction in cooling load of 40% to 50% for the summer involved. However, because of load fluctuations, systems in some buildings had to be adjusted frequently—as much as twice a day. It should be noted that there may be problems with this technique when high humidity is involved. During the winter season, the outside air and return air dampers were adjusted slightly so that supply air temperature was between 64° and 70°, instead of the usual 55°, depending on the conditions in the area served. In some cases, such as when an HVAC system is serving a computer room, temperature and humidity conditions must be maintained within certain specific limits. In such cases, adjustments to a terminal reheat system must be made with caution.

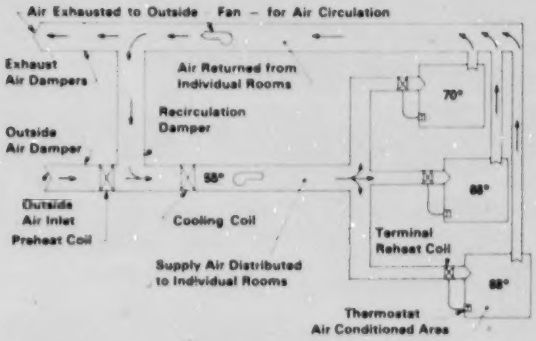


Figure 4.4. Terminal Reheat System

Resetting Deck Temperatures in Dual Duct Systems

The constant volume dual duct system, as shown in figure 4.5, is similar in its energy use and waste to the terminal reheat system. Here again, each space is provided with both heated and cooled air which—before entering the space—passes through a mixing box that regulates the amount of heated and cooled air to attain the desired temperature.

A dual duct system may also be modified. During winter months, the temperature of the cold air is allowed to rise to 60° to 70° by adjusting the outside air and return air dampers so that less hot air is necessary. During the summer season, by using cooled air at 64° instead of 55°, much less heating energy is required to attain desired temperatures. Dual duct systems, like terminal reheat systems, are used to achieve accurate control over temperature and humidity. In some special cases, adjustments must be made with extreme caution.

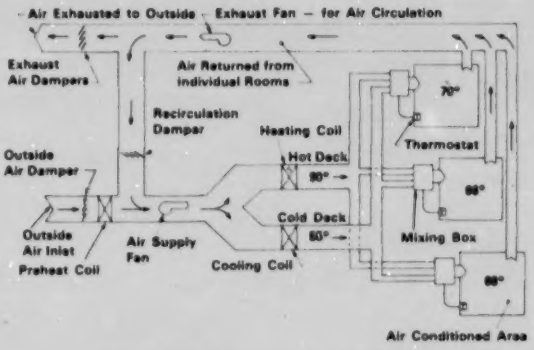


Figure 4.5. Dual Duct System

Improvement in Central Plant Operations

The source of an institution's energy—the central plant—can probably be modified to yield significant low-cost energy savings. Several of the major steps that can be taken to improve the operating efficiency of central cooling and heating plants are:

Chiller Plant

1. Operate condenser or water system at lower temperatures.
2. Sequence chiller operation.
3. Operate only necessary chilled water pumps and cooling tower fans.
4. Elevate chilled water temperatures when humidity conditions permit.

Boiler Plant

1. Operate boilers at lower pressure and temperatures.
2. Consider elimination of hot standby boilers since, in many cases, a boiler failure will not cause serious hardship.
3. Operate only necessary water heating pumps.
4. Establish a uniform firing rate instead of

modulating between high and low firing rates.

5. Adjust air-fuel ratios.

Operational logs should be kept up-to-date on a daily basis, since it is only by having performance data on hand that determination of the impact of modifications can be made. See appendix A-3 for an example of how efficiencies may be increased in a central boiler plant.

Adjustment and Calibration of Controls

The controls originally installed in a building probably were designed with initial cost in mind rather than energy efficiency. In addition, just a few years of use without adequate maintenance can cause even the best controls to go out of calibration. A well-planned program of control adjustment and calibration is thus an important part of any energy management program, since not only will it save energy, but will also improve comfort and reduce complaints.

A program of control adjustment and calibration of automatic controls should include the following:

1. Inspect and test for proper operation.
2. Calibrate thermostats and gauges.
3. Adjust controllers.
4. Adjust air dampers to insure tight closing.

Reduction of Domestic Hot Water Energy Consumption

The amount of energy consumed in heating hot water varies from building to building, depending on the type of structure, usage, occupancy, and time of day. Facilities that include cafeterias and dormitories generally use a higher percentage of energy for hot water than facilities without these features. The following should be considered relative to energy conservation and hot water.

1. Reduce domestic hot water temperature.
   a. Refer to health and food handling codes for minimum temperature specification for areas involving health or research services.
   b. Reduce generating and storage temperature levels to the minimum required for washing hands, usually about 100° to 110°.
   c. Boost hot water temperature locally for kitchens and other areas where it is needed, rather than providing higher than necessary temperatures for an entire building.
2. Reduce the quantity of domestic hot water used.
   a. Adjust valves for minimum water use.
   b. Insert orifices in hot water pipes to reduce flows.
   c. Consider installing flow-limiting shower heads (two to three gallons per minute).
   d. Consider installing spring-activated hot water taps.
   e. Refer to plumbing codes, if applicable, for hot water supply requirements.
3. Improve efficiency of storage and distribution equipment.
   a. Repair insulation on hot water pipes.
   b. Where forced circulation of hot water is used, shut off pumps when the building is unoccupied. When hot water usage is light, consider using gravity circulation without the pump.
   c. Repair leaky faucets.
4. Consideration should also be given to distilled water production and consumption, since in many cases this can be a very inefficient use of energy and water. One university made major still modifications and realized a payback period of two to three years.

Reduction of Elevator Energy Consumption

The amount of power required to operate an elevator is a function of the height of the building, the number of elevator stops, the passenger capacity and load factors, and the efficiency of the hoisting mechanism. For example, a 2,500-lb. capacity "local" elevator making 150 stops per car-mile consumes about five kWh per car-mile, while an "express" elevator making 75 stops per car-mile consumes about four kWh. Consumption also varies among elevators of the same capacity, depending on the type of hoisting motor and control, the kind of service, the amount of load offset by the counterweight, and whether the elevator is hydraulic, geared, or gearless.

The following steps can be taken to reduce energy consumed by elevators:

1. Examine usage; shut down unneeded elevators.

2. Turn off motor-generator set when not in use.
3. Encourage walking.

Equipment Maintenance

While a properly planned and executed program of equipment maintenance may not be immediately synonymous with energy conservation, such a program can in fact contribute significantly to reducing energy waste. Equipment that is correctly and regularly serviced and maintained will last longer and will operate more efficiently, thereby requiring less energy than equipment that is ignored. For example, a scale build-up of 1/32 inch on condenser tubes can reduce the efficiency of a chiller by 25%, while also cutting down on the effective life of the unit. When one considers the cost of equipment replacement and the cost of energy to run equipment, the value of extended years of energy-efficient service by the equipment will almost inevitably be greater than the cost of providing proper maintenance.

If an equipment maintenance program has already been implemented, it is important to review maintenance procedures on a regular basis to make certain that schedules are being followed, that responsibility for specific tasks is clear and that equipment is in fact in good working order. If a maintenance program has not yet been established, it is advisable to do so, since each piece of equipment requires a certain amount of care and upkeep in order to run efficiently. If uncertainty exists as to the type of maintenance required, the equipment manufacturer should be contacted for further information. A maintenance schedule should be written, which lists equipment to be serviced, when it is to be serviced, and by whom.

As with most other aspects of effective energy management, accurate and thorough record-keeping of equipment maintenance rendered is critically important. Making certain that schedules are kept, that repairs are recorded, that frequency of service is logged and that malfunctions are reported are just some of the data that will be of value in monitoring the progress and effect of an equipment maintenance program.

It is also important to recognize that proper maintenance depends on those responsible for performing it. For maintenance personnel to do their work well, they must be given assistance in the form of:

1. Scheduling for equipment to be serviced, work to be performed, and frequency of service.
2. Training for correct maintenance procedures, early warning signals, and appropriate corrective actions.
3. Performance checks to insure that work is being done well, and if not, so that remedial training can be provided.
4. Credit and recognition for jobs well done and energy saved.

The ability to instill in maintenance personnel a desire to work enthusiastically on an energy management program, as well as the ability to build a competent energy management organization, will be of critical importance to the success of a program.

Reduction of Water Waste

Water is in short supply in many areas. In addition to the scarcity of water, energy must be expended to pump it from its source to the point of use. Several of the quick fix methods that can be used for reducing unnecessary water consumption include:

1. Turning off unused equipment.
2. Repairing system leaks.
3. Adjusting cooling tower bleed-off rate.
4. Metering cooling tower make-up water.
5. Watering grounds properly.
6. Using spigot-type drinking fountains.
7. Repairing solenoid valves and adjusting for proper compression on refrigeration compressors.

Efficient Use of Buildings and Space

Energy-efficient utilization of buildings and spaces within buildings can result in further elimination of energy waste. Many facilities remain open 24 hours a day, seven days a week, even when not being used, while other facilities are kept open for use by only a few persons or for one or two classes. Reviews of building occupancy schedules, intensity of energy use by a facility, and alternate spaces that could be employed often result in several clear, low-cost ways for reducing energy consumption.

Such measures as the consolidation of classes

and extracurricular activities into fewer buildings, closing of certain facilities during the evening, weekend, and vacation periods, and the scheduling of classroom use on a campus-wide basis should be given consideration. The results achieved by such measures are impressive. One university held summer courses in three buildings instead of the originally planned five structures. This consolidation resulted in closing two buildings, thereby saving $31,000 in energy costs.

Refit

Energy conservation measures falling into the refit category require a modest amount of capital investment and will normally yield an additional 10% to 15% reduction in energy consumption over and above the reduction achieved in quick fix. Most refit measures have a payback period of from six months to three years, depending on the measure involved and the capital invested. Since refit modifications involve investment, a careful engineering analysis of proposed modifications should be undertaken in order to use capital wisely. Such studies may be undertaken using in-house engineering and energy management expertise. Often, however, due to limited staff availability and capability, as well as the complex nature of the systems being analyzed for refit modifications, outside advice is required. Many excellent engineering and energy management consultants are available, but there are also a growing number of "energy experts" who have little experience and knowledge of the problems on the modern campus.

If outside assistance is sought for an energy management program, the suggestions below should be considered in order to help insure that the type of guidance that will be most beneficial is received. Normally, a consultant should (1) conduct an energy survey that analyzes present energy use and (2) provide a detailed report indicating recommended energy conservation options, and the predicted energy savings for each proposed modification. This survey and report would then be followed by predicted payback periods for each option, as well as recommendations for which options are most attractive. After review and discussion, if the consultant is instructed to proceed, plans and specifications should be prepared for the modifications. Such plans should include instructions for revised fan drives, new air balance figures for revised ft.^{3}/min. deliveries to various spaces, and revision of design air and liquid balance data. After modifications have been completed, the consultant should be asked to provide a monitored completion report showing revised system design, completed air and liquid balance results, new operating instructions, and updated as-built drawings showing all changes made to the systems.

Energy use in modified structures should then be carefully monitored to compare actual energy consumption reductions with those predicted in the original analysis prepared by the consultant. Problems experienced as a result of conservation modifications should be brought to the attention of the consultant so that he may assist with corrective measures.

Since there is a limit on the amount of money available for refit modifications, it is necessary to be sensitive to the need for establishing refit priorities. The criteria used to establish such priorities should reflect the particular circumstances of an institution. However, in most cases it has proved beneficial to concentrate refit efforts on measures that provide substantial energy savings with rapid payback. The systems most often targeted for refit, based on this criterion, are those that operate 24 hours a day and, in particular, those that are inherently wasteful of energy, such as dual duct and terminal reheat systems, as well as systems having excessively high fan horsepowers and static pressures.

Some of the refit measures that are effective for colleges and universities include:

1. Adding zone demand reset controls.
2. Implementing air volume reductions.
3. Using outdoor air for cooling.
4. Replacing inefficient outdoor air dampers and damper operators.
5. Recirculating exhaust air where practical.
6. Isolating off-line boilers.
7. Isolating off-line chillers.
8. Reducing transmission heat losses and gains.
9. Modifying lighting controls, fixtures, and space characteristics.

These measures are listed in order of general priority, but circumstances at an institution may require a different order of implementation.

There are, of course, many other refit measures that can be employed, some of which are listed in appendix B.

Addition to Zone Demand Reset Controls to Modify Terminal Reheat and Dual Duct Systems

As previously noted, terminal reheat and dual duct systems use excessive amounts of energy. The quick fix measures for achieving energy consumption reduction in these systems involve manual control. However, several control manufacturers have pre-engineered electronic and pneumatic controls that can do this same work automatically.

As shown in the diagram for a terminal reheat system (figure 4.6), the zone requiring the least amount of reheat is found by comparing a signal from each zone to a reference point. Until this zone is found, the supply air temperature to the reheat coils is progressively increased. When the reference point is reached, less demanding zones continue to use just enough reheat to satisfy the individual zone control. In this case, some reheating will occur well into the summer because of system diversity; all zones do not peak simultaneously. Nonetheless, by cooling only far enough to meet the most demanding zone, reheating is minimized.

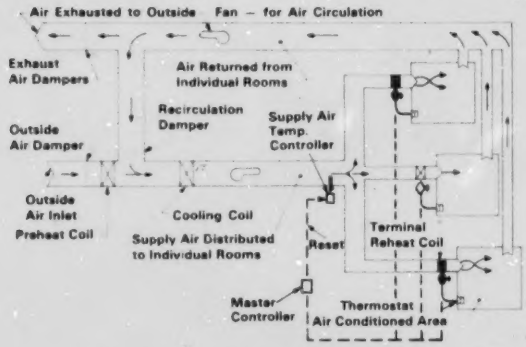


Figure 4.6. Terminal Reheat System

As shown in the diagram for a dual duct system (figure 4.7), both cold deck and hot deck temperatures are controlled to meet the most demanding cooling and heating zone. Presumably, there will be only one zone that will equal the "full cooling" reference signal. Until the most demanding zone control signal equals the reference, the cold deck air temperature is progressively increased. Likewise, a "full heating" reference is established to determine the hot deck temperature. The lowest hot deck temperature that will meet the load in the most demanding zone is found. Under summer conditions, the hot deck temperature is reset so low that it becomes unprocessed "return air." Compared to a non-reset, dual duct system, deck temperature resetting can often result in a savings of 10% of the total utility cost for a building.

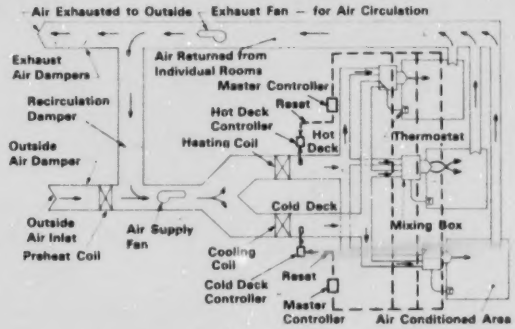


Figure 4.7. Dual Duct System

Variable Volume. Mechanical systems such as terminal reheat and dual duct are constant volume (fixed volume) systems. That is, a constant volume of air is always being treated—heated or cooled—no matter what the volume requirements of the spaces or zones served. There is, however, a method for changing this constant volume situation by conversion to a variable volume system. Such conversion is accomplished by adding a variable volume device and a fan control within the ducts of a terminal reheat or dual duct system. Unlike the constant volume of air that characterizes the terminal reheat and dual duct systems, the variable volume device and fan control permit the reduction of air volume flowing into a space (variable volume), allowing only the quantity of air to enter that is necessary to heat or cool. As soon as the space or zone has been provided with a sufficient volume of air, the variable volume system throttles down air supply to the zone control. The supply air fan senses the reduction, causing the modulation for fan inlet vanes. The total volume of air drawn into the system and passed by the fan thereby reduces the horsepower necessary to drive the fan.

This type of variable volume system offers

the further advantage of reducing air supplied to exterior zones of a building during the heating mode by up to 50%. Where formerly the fixed volume systems always processed the same volume of air, whether heating or cooling, the variable volume system permits the introduction of fewer cubic feet of air per minute into a space. Since it generally takes more air to produce chill than heat, the heating mode now takes only that amount of air necessary for heating.

Similarly, because air volume can be reduced or almost completely throttled down in some cases, heat or reheat to interior spaces can be nearly eliminated. That is to say, if an interior space is not receiving any or much air because of its proximity to other treated spaces, the need to heat or reheat the air not being used for the space is eliminated.

exterior room, a regulated volume of warm and cold air is being introduced to reach an ambient temperature. It can be readily seen that had this been a standard dual duct system, the same volume of hot and cold air would have been introduced into each room, thereby wasting energy.

It should be noted, however, that the implementation of a variable volume system can be complex and expensive, depending on the type of system involved. Nonetheless, this type of refit modification should be given serious consideration for its energy-saving potential.

Addition of Zone Demand Reset Controls for Multizone Systems

A multizone system such as that illustrated in figure 4.9 heats and cools several zones—each with different load requirements—from

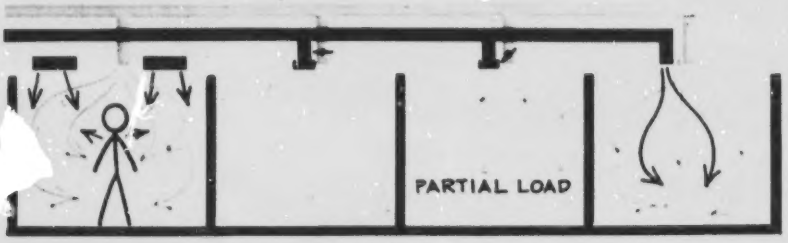


Figure 4.8. Effect of Implementing Variable Air Volume in Interior Rooms

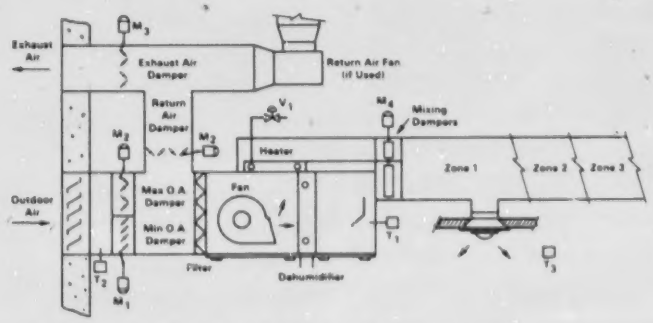


Figure 4.9. Typical Multizone System

A simple method for implementing a variable volume system on certain dual duct systems is shown in figure 4.8. In this system, hot air ducts into a room are simply blanked off so that in the case of an interior room in which someone is working with lights on—creating heat—only cold air is introduced. In the next room, no air is being introduced, while in the third, some warm air is provided due to a partial load within the room. Finally, in the

a single central unit. A thermostat in each zone controls dampers at the unit, which mix the hot and cold air to meet the varying load requirements of the zone involved. As with dual duct systems, multizone systems can also be refitted with zone demand control systems, as shown in figure 4.10.

Each zone thermostat transmits a signal indicating the difference between the actual temperature in the zone or space and the thermo-

55

stat setting for that zone or space. The signal is then transmitted to two places: first, it goes to the individual damper control or zone actuator which, based on the temperature differential involved, controls the dampers for the zone or space involved; it also goes into an electronic device called a discriminator network, which compares the signals coming in from all zones. The temperature of the cold deck is determined by the amount of cooling required by the zone or space that needs the most cooling. Likewise, the temperature of the hot deck is determined by the zone that needs the most heat. These two zones are called critical zones, and the amount of heating or cooling employed is a direct function of the magnitude of the heating or cooling demand in the critical zones. Energy is saved in this refit modification because deck temperatures are varied according to need rather than remaining constant and wasteful.

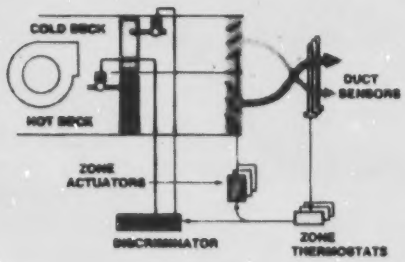


Figure 4.10. Zone Demand Control

Implementation of Air Volume Reduction

Since reduced lighting levels in a space result in reduced cooling requirements for the space, an opportunity exists to reduce the volume of supply air coming from the air handling unit. Reduced supply air volume results not only in savings of the energy required for heating and cooling this air, but also of the energy required to power fan motors in the system. These supply air volume reductions can be achieved either by changing fan motor sheaves or by using vortex dampers.

Lighting modifications implemented with other changes affecting ventilation supply and exhaust air volume result in substantial savings of energy, since fan brake horsepower varies with the cube of the air volume. For example, if air quantity is cut back by 10%, fan power input is reduced by 27%. In many cases, this type of modification not only provides substantial energy savings, but also fast payback.

Economizer Cycle—Use of Outdoor Air for Cooling

Another refit modification that should be given consideration is the installation of "economizer cycle" controls. An economizer cycle is defined as the use of cool outside air rather than mechanical refrigeration to reduce space temperature. Such a cycle is regulated by an outdoor air temperature sensor that discontinues compressor operation when outdoor temperature falls below the design supply temperature, normally 50° to 60°. Cooler outside air is then drawn into the system and used to reduce space temperature.

Typically, the changeover to an economizer cycle occurs when outside air reaches a temperature of approximately 55°. At this temperature, both the indoor design temperature and the humidity level within the occupied space can be maintained. In most building systems, however, it usually is economically feasible to use outside air for cooling whenever the total heat content (or enthalpy) of the outside air is less than that of air being recirculated through the system (return air).

It should be noted, however, that an economizer cycle requires the continuous use of a return air fan that is connected to two dampers. If outside air is at 55°F, the return air fan draws the outside air through the system and exhausts it through the open relief damper. If the outside air is cooler than 55°F, it is mixed with recirculated air that is pumped back into the system via the supply damper on the return air fan rather than being exhausted through the relief damper. The return air fan also creates negative pressure in a room as it draws air out, thereby allowing the outside air to flow freely into the space being cooled. Since it is necessary to install a return air fan system to take advantage of an economizer cycle, careful consideration must be given to the cost of such an installation and to the fact that the return air fan will use energy.

Other factors should also be considered when using outdoor air for cooling, such as the type of system installed, climate, building occupancy patterns, and zoning. Nevertheless, this type of modification, properly implemented, can lead to significant energy savings.

Replacement of Leaky Outdoor Air Dampers

Many ventilation systems, especially roof-top units, were initially constructed with low-quality air dampers that do not allow accurate control. In some cases, even when dampers are fully closed, air leaks are found in quantities that exceed minimum outdoor air requirements. Leaky outdoor air dampers should be replaced with high-quality, opposed-blade dampers with air seals at the blade edges and ends, as shown in figure 4.11.

Recirculation of Exhaust Air

Air that is exhausted must be replaced, or "made up," by outside air. Make-up air must be conditioned by a mechanical system, a process that requires energy. One method for reducing the energy consumed in make-up conditioning involves the use of exhaust air by recirculation. This can be facilitated by installing activated carbon filters, which eliminate odors from the air, as shown in figure 4.12. A filter would be used in the case of air recirculation from such areas as kitchens and dining rooms. Before proceeding with this type of modification, it is necessary to check local codes to make certain that the modification is permissible. This type of modification will not be useful or permissible in many laboratory areas, where the nature of certain experiments does not allow the reuse of air.

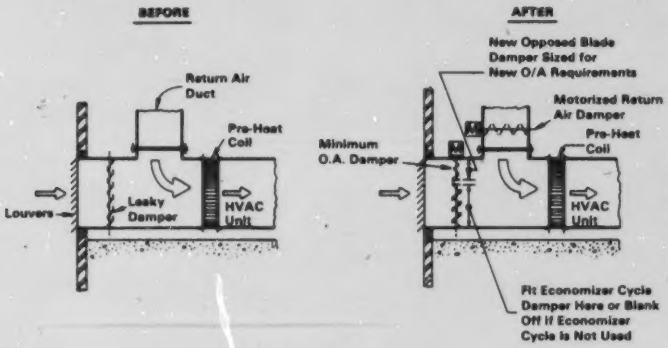


Figure 4.11. Outdoor Air Dampers

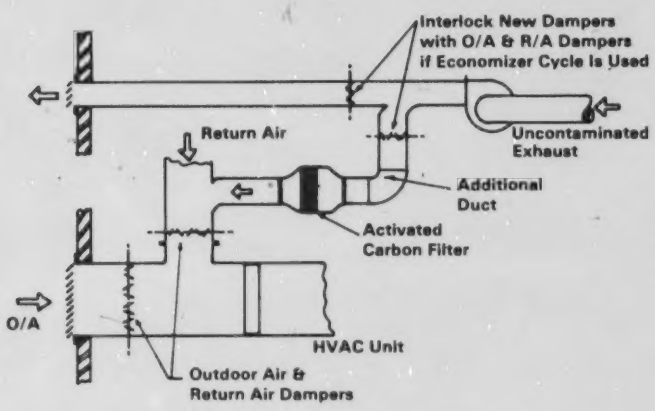


Figure 4.12. Exhaust Recirculation System

If economizer cooling is used in summer, the outdoor air dampers must be sized to pass the full volume of air required by the supply fan. If, however, economizer cooling is not contemplated and minimum quantities of outdoor air will be used year-round, then the size of the outdoor air intake louvers and damper can often be reduced and the unused portion of the outdoor air inlet blanked off.

A system of contaminant and odor removal

through electrical charge control of submicron particles has been developed, which provides excellent results in reclamation of exhaust air, with subsequent reductions in outdoor air heating and cooling. This system has been applied to hospital operating rooms, animal facilities, and toilet exhausts. A relatively simple electrode unit charges particles, causing them to join with suspended fine particles, whereby they become of sufficient size to be caught by high-efficiency mechanical filters.

Isolation of Off-Line Boilers

Light heating loads on a multiple boiler installation are often handled by one on-line boiler, with remaining boilers idling on standby. Idling boilers consume energy, so unless such a boiler is scheduled for imminent use, it should be secured and isolated from the heating system by closing valves, and from the stack and chimney by closing dampers.

As shown in figure 4.13, large boilers can be fitted with by-pass valves and regulating orifices to permit just the minimum flow needed in order to keep the boilers warm and thereby avoid thermal stress when they are brought on line again. Prior to bringing the boiler on line again, closed dampers must be reopened.

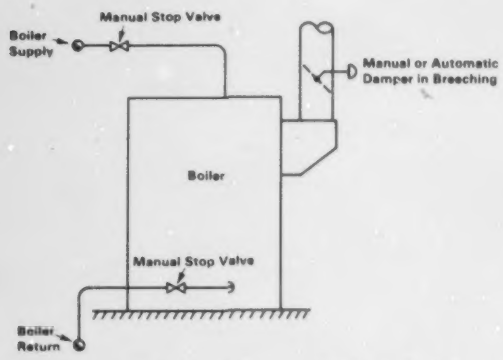


Figure 4.13. Isolation of Off-Line Boilers

Isolation of Off-Line Chillers

Light cooling loads on a multiple chiller installation are often handled by circulating chilled water through all chillers, even though only one chiller needs to be operating—or on line. This procedure wastes pump energy by maintaining an unnecessarily high rate of water flow through the system. In addition, because water still flows through the off-line chillers—an action known as the "by-pass effect"—the remaining on-line chiller must produce chilled water at lower temperatures to offset the temperature increase that results when water flowing through the off-line chillers mixes with the low-temperature water coming from the on-line chiller. By installing isolating valves as shown in figure 4.14, off-line chillers can be isolated and chilled water flow rate reduced. Also, unnecessary chilled water pumps can be deactivated to lighten the load. If multiple chilled water pumps are not installed, consideration should be given to installing additional pumps or a multispeed drive on the present pump.

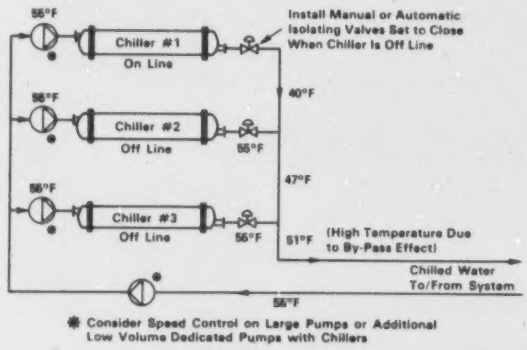


Figure 4.14. By-Pass Through Off-Line Chillers

Reduction of Transmission Heat Losses and Heat Gains

Buildings lose heat during the heating season and gain it during the cooling season through the process of heat transmission, and the energy required to offset heat transmission losses and gains can be substantial. It may be advisable to have an infrared survey conducted in order to help indicate where such losses and gains are occurring, and which losses and gains are more severe than others.

A variety of measures can be taken to offset transmission heat losses and gains, most of which are detailed in appendix B. The two most commonly applied measures involve the use of insulation and solar controls; however, the cost of these modifications can be substantial, and paybacks may vary widely. Like all refit measures, these modifications should be preceded by an engineering study.

Modification of Lighting Controls, Fixtures, and Space Characteristics

In many cases existing lighting systems were designed without prior knowledge of how the space to be lighted would be used, once the building was completed. This has often led to overillumination, inconvenient placement of controls, lack of adequate controls, and specification of lamps and fixtures that—by current standards—do not lend themselves to energy efficiency. Correction of overillumination and lamp inefficiency can be handled by a variety of quick fix measures that were discussed earlier, as well as by certain refit measures, such as those listed below.

1. For controls, the installation of (a) switches enabling deactivation of lights in unoccupied areas, (b) time switches on lights used in areas of light occupancy, (c) photocells or astronomical timers for exterior lighting, and (d) neon pilot lights to indicate when lights are on in adjacent, enclosed areas.

An example of how certain refit measures, coupled with certain quick fix measures, can achieve savings is shown in figure 4.15, which summarizes savings achieved by Ohio State University. In this case, the modifications implemented included shutdown of HVAC equipment during unoccupied periods, reduction of lighting levels and therefore reductions in air volume, conversion to a variable volume system, and resetting of mixed air temperatures. As can be seen, consumption of electricity was reduced by 25% and gas by 57% to achieve a 44% savings in one building. These savings were accomplished without any detrimental effect on the comfort, safety, and security of building users.

Systems Convert

Systems convert modifications are those requiring substantial capital investment to convert or replace existing systems with energy-using equipment. Because such conversion or replacement requires the use of sophisticated

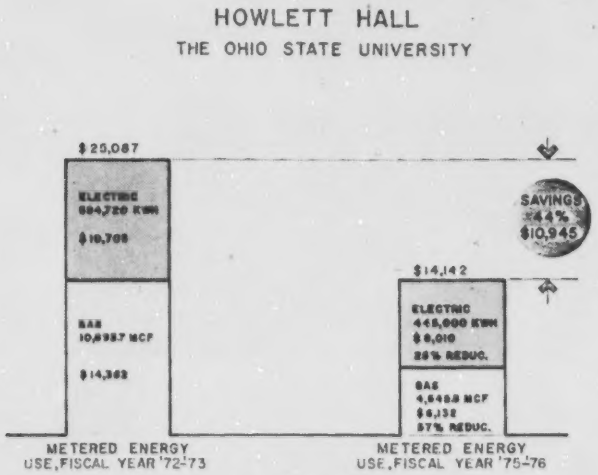


Figure 4.15. Energy Savings
(calculated using September 1975 costs of $1.32/mcf and $0.018/kWh)

2. For fixtures, replacement of incandescent fixtures, where feasible, with energy-efficient fixtures such as fluorescent.
3. For surface characteristics, (a) application of light-colored or reflective surfaces to ceilings and walls to enhance light quality and (b) lowering the height of partitions, where possible, to take maximum advantage of available lighting.

technology and hardware, and therefore capital investment, systems convert modifications will generally be characterized by payback periods ranging from three to five years. Such conversions, where applicable, will usually yield an additional 10% savings in energy use above those realized as a result of quick fix and refit modifications.

As with refit modifications, an engineering

analysis of all proposed systems convert measures is necessary. These modifications may not be appropriate or practical for many colleges and universities; however, institutions engaged in scientific research and the provision of health care, and which are therefore energy-intensive, would do well to examine systems convert options.

As an institution initiates systems convert modifications in certain areas, it will also continue to undertake quick fix and refit modifications in other areas. That is, a simultaneous as well as an evolutionary process is involved. For example, as an institution moves into a computerized central control system, it may also be running a concurrent refit and/or quick fix program.

Some of the systems convert modifications implemented by colleges and universities are central control system application, heat reclamation, and solar energy utilization.

Central Control Systems

A central control system provides constant surveillance of a building and assists in making efficient and effective use of physical plant systems and personnel. Such systems are usually connected in the larger, more complex buildings or groups of buildings, where energy use tends to be high due to extended occupancy or to use of special equipment.

Central control systems vary from relatively simple types designed to perform a few functions to progressively complex types performing a variety of functions. Such systems should be tailored to the present requirements of the equipment they will control. An overview of the central control system capacity should, however, be made at the time of initial design to incorporate provisions for the expansion of system hardware and software capacity when investment money permits. A feasibility study should be performed prior to proceeding; the use of a consultant is recommended, especially where in-house engineering expertise is not available.

An initial central control installation may be composed of a control console and central processing unit with one printer programmed to perform only start/stop and simple reset functions. Optimization of system operation would probably occur manually at the central console, based on decisions made by operating staff. By judicious use of this capability, engineering staff can ultimately operate most systems from a central console. Physical plant critical alarms will be reported automatically at the console; the operator will be able to scan the system in alarm, analyze the fault, and dispatch maintenance personnel to make repairs. Maintenance alarm summaries can be made available on demand, which will lead to proper work scheduling and maximum use of maintenance personnel.

In addition to the above functions, a central control system can be programmed to (1) monitor off-normal conditions, (2) monitor fire alarm and security devices, (3) monitor operating conditions of HVAC systems and reschedule set points, (4) monitor selected portions of HVAC systems and store information, (5) limit peak electrical demand, and (6) assist in achieving optimal operation of all systems.

Types of Systems. Proprietary central computerized control systems are marketed by the major temperature control manufacturers. All these systems have common features and can handle a similar range of tasks. However, each manufacturer uses coding and computer languages unique to its system; they cannot be decoded by any other system. Thus, once a basic system has been selected and installed, all subsequent additions will probably have to be purchased from the same manufacturer. It is therefore important when selecting a system to thoroughly investigate its expansion potential in relation to future needs.

Central computer control systems are usually modular in design (see figure 4.16). Additional hardware and software can be added if necessary provisions have been made in the basic system. Each manufacturer's system comprises standard off-the-shelf hardware, but the application is always tailored to the specific project. Basically, any system is composed of four major parts:

1. Interface panels, which are located at strategic points throughout the building (usually equipment rooms). These panels form the focal point of all signals to and from a particular area.
2. Transmission system, between the central console and all interface panels. This transmission system can be a simple, single-core cable for digital transmission

or a multicore cable for multiplex transmission.

3. Central control console and associated hardware, located in a control room.
4. Software or program for the system. Software input is made via magnetic tapes, paper tapes, or cards containing the basic operating instructions for the computer. Software input is stored in the form of "bits" of information either in core memory or in bulk memory (cheaper than core for large quantities of data).

when used in conjunction with other programs and routines. In its simplest form, a start-stop program is arranged to start and stop equipment according to a predetermined schedule. The program can also open and close dampers, turn lights on and off, and reset temperatures for occupied and unoccupied situations. Manual override can be provided with automatic reversion to program control at the end of an occupied or unoccupied period. Interface with other programs allows the basic program to be overridden and equipment turned on and off to

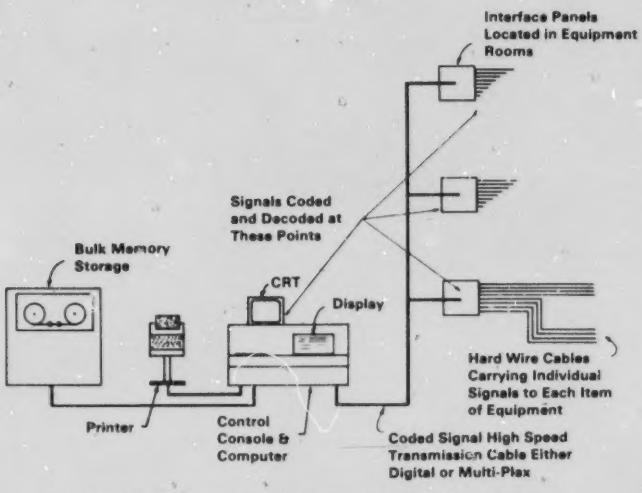

Interface Panels Located in Equipment Rooms
Signals Coded and Decoded at These Points
Bulk Memory Storage
CRT
Display
Hard Wire Cables Carrying Individual Signals to Each Item of Equipment
Printer
Control Console & Computer
Coded Signal High Speed Transmission Cable Either Digital or Multi-Plex

Figure 4.16. Central Computer Control System

Typical programs used in a central computer control system are the executive program, start-stop program, load shedding program, optimizing programs, reset programs, and alarm programs. These are discussed in detail below.

The *executive program* is essential for the function of the computer itself, as it keeps track of real time, controls the priority of signal processing, directs information in and out of memory, controls the operation of all associated hardware, and encodes/decodes incoming and outgoing signals. An essential part of this program is the orderly shutdown of the computer on power failure to insure that all information is safely stored in permanent memory before power is lost. Systems that store information in a memory that can be damaged by power failure should be avoided.

A *start-stop program* is the simplest type of program, but with modifications, it becomes the most effective energy saver, particularly handle changing situations. Start sequences can be arranged in a "cascade" manner to avoid simultaneous starting of many pieces of equipment, thereby avoiding the cumulative effect of currents that cause a high peak electrical demand.

The *load shedding program* is used in conjunction with the start-stop program to override normal operation and to turn off equipment as a predetermined electrical peak load value is approached. In its simplest form, the program would shut down selected equipment according to the measurement of peak load. The program can be modified to include a rolling priority feature, which allows equipment to be shut down on an assigned priority basis for a predetermined period of time after which it is returned to service and a lower priority piece of equipment turned off. The rolling priority would be activated only when a predetermined peak load value is approached,

and the equipment turned off would be limited to that necessary to make certain that the load remains below a given level.

Interface of this program with an electrical profile routine allows development of a continuous profile of electrical demand and calculation of predicted load in the immediate future. This predicted load would then be used to initiate the rolling priority sequence in order to alter the slope of the prediction curve. The current maximum peak load experienced in the previous eleven months would also be held in memory and used as the criterion for load shedding. This value could be constantly modified, based on monitored information.

Optimizing programs tend to be more sophisticated than the others so far described, requiring interface with an arithmetic routine to allow optimum settings to be calculated. The optimizing program interfaces with the start-stop program, load shedding program, and reset program to modify operation of equipment. Optimizing programs can provide economizer cycle control of outdoor air according to enthalpy and loads. Chilled water and boiler water temperatures can also be modified to provide optimum equipment operation according to load. Certain optimizing programs are available from the manufacturer's library, but others may have to be written especially for the purpose.

Reset programs are designed to reset the control points of thermostats and pressure controllers and to interface with load shedding and optimizing programs. In place of, or in addition to, turning off equipment for load shedding and energy conservation, loads can be trimmed, i.e., if a peak load is approaching, space conditions can be reset to reduce cooling or heating loads; outdoor air dampers can also be reset in this type of program.

Alarm programs report alarms generated either outside the computer (fire alarm pull boxes, high pressure in boilers, etc.) or in computer software. Upper and lower limits can be set in software for any monitored point, and an alarm will go off when these limits are reached. Alarm programs can also be interfaced with the start-stop program to monitor hours of equipment run, then reporting a maintenance alarm when a designated number of running hours is reached. Information on maintenance required can be stored in memory and printed when the alarm is reported.

A word of caution: sophisticated computer control systems are not substitutes for a well-planned program of preventive maintenance, quick fix, and refit. These types of systems should not be implemented until there are sufficient understanding and manual control of existing systems. A central computerized control system will not transform an energy-inefficient campus into an efficient user of energy.

Heat Reclamation Systems

Heat reclamation is defined as the recovery and utilization of heat energy that would otherwise be wasted. Waste heat can be substituted for a portion of the heat energy that would normally be required for heating and cooling and for domestic hot water systems. Heat recovery conserves energy, reduces operating costs, and reduces peak loads. However, heat recovery systems generally involve considerable expense and thus return on investment for such systems may not be as attractive as that for other types of modifications. A variety of devices can be utilized to reclaim waste heat, but these are generally more practical as installations on new buildings.

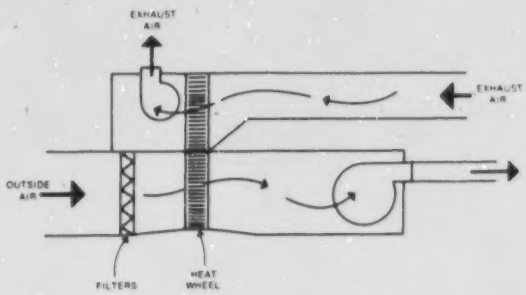


Figure 4.17. Rotary Heat Exchanger

Rotary Heat Exchanger. A device often found on power plants, the rotary heat exchanger uses a heat transfer medium in the form of a cylindrical drum or wheel (figure 4.17). When the drum is rotated slowly between the supply air stream and the exhausted air stream, it absorbs heat from the warmer air stream and rejects heat to the cooler air stream. While the supply and exhaust ducts must usually be located near each other in order to use this system, close proximity can occasionally be an

obstacle, especially when exhaust streams are contaminated. In such cases, purge sections must be added to the wheel and special filtration may be necessary in the supply air stream.

Air-to-Air Exchangers. These transfer heat directly from one air stream to another through direct contact on either side of a metal heat transfer surface (figure 4.18). At Michigan State's central food service salad preparation area, heat from an 80-gallon and a 40-gallon steam kettle is collected by a hood and processed through a heat exchanger, which heats the incoming make-up air. The cost of installation was $1,400; the cost avoidance is $400 a year.

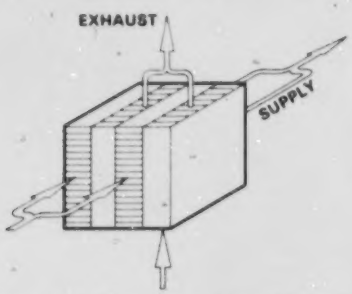


Figure 4.18. Plate Type Heat Exchanger

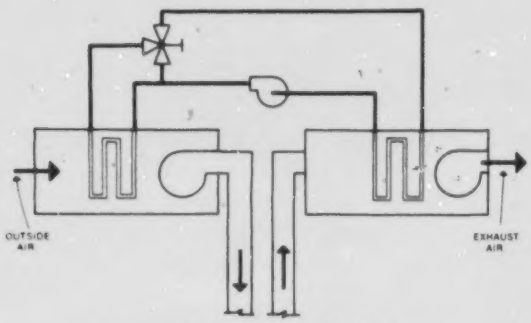


Figure 4.19. Run-Around Coil System

Run-Around-Coil System. This system is comprised of two or more extended surface fin coils installed in air ducts and interconnected by piping (Figure 4.19). The heat exchanger fluid, consisting of ethylene glycol and water, is circulated through the system by a pump, removing heat from the hot air stream and rejecting it into the cold air stream. A run-around-coil system may be used in winter to recover heat from warm exhaust air for use in preheating cold outdoor air, and in summer to cool hot outdoor air by rejecting heat into cooler exhaust air.

The coil type exchanger has the advantage of permitting heat transfer between supply and exhaust systems in widely separated portions of a building, since coils are installed in each of the intake and exhaust ducts and are connected only by piping. It is relatively easy to run piping for long distances through a structure, interconnecting a number of separate exhaust and fresh air systems to form one complete system.

Heat Pipe Systems. Heat pipes are composed of extended-surface, finned tubes extending between adjacent air ducts (figure 4.20). The tubes run continuously from one duct to the other, and they are on the same horizontal plane. Each tube contains liquid refrigerant, which evaporates at the warm end of the tube, absorbing heat from the warm air stream. The evaporated refrigerant then migrates as a gas to the cold end of the tube, where it condenses and releases heat into the cold air stream. The condensed liquid then runs back to the hot end of the tube to complete the cycle. To operate effectively, the heat tubes must slope down from the cold end to the hot end, and accurate control of the slope must be provided. Heat pipes running between hot and cold air ducts can be used only when ducts are immediately adajcent to each other, and thus some modification of existing ductwork may be necessary for installation of this type of system.

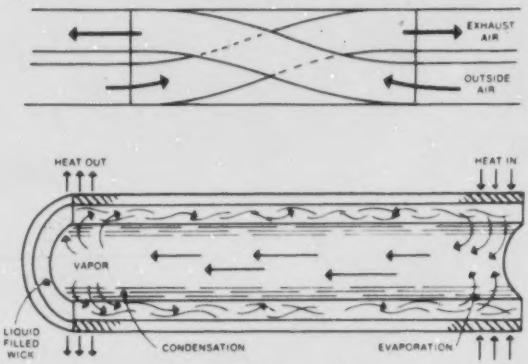


Figure 4.20. Heat Pipe

Shell and Tube Heat Exchangers. These can be used to exchange heat in the following configurations: (1) liquid-to-liquid, (2) steam-to-liquid, and (3) gas-to-liquid. All three configurations are commercially available in a wide range of sizes and outputs, with reliable heat

exchange data. A particularly favorable application of these exchangers involves the capturing of energy from hot condensate, as shown in figure 4.21, or from hot refrigerant gas, condenser water, and hot drain lines from kitchens and laundries.

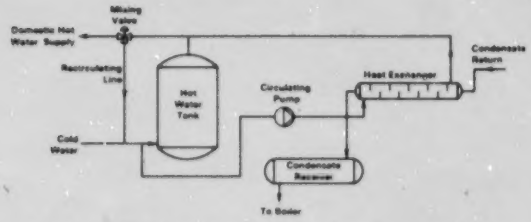


Figure 4.21. Condensate Heat Recovery System

This type of system is employed by Michigan State in the campus laundry, where heat is recovered from laundry waste water before it is discharged to the sewer. A heat exchanger system uses the 180°F soiled washwater to heat the incoming fresh water from 50° to 130°. Condensate from the steam-heated ironing machines is also used, and raises the water temperature to 170°. The hot water heater requires only enough new energy to add 10° to raise the final water temperature to 180°. The soiled washwater is finally discharged to the sewer at 72°, and the condensate is returned to the power plant at 170°. The cost of installation was $46,000; cost avoidance is $18,000 minimum per year, based on processing 125,000 pounds of dry laundry per week.

Incinerators. Incinerators burning solid waste produce 6,000 Btu/lb. of common trash. Special heat recovery incinerators are available in sizes down to approximately 100 lbs./hr. burning rate, which generates about 450,000 Btu/hr. Typical applications are absorption refrigeration, heating, and domestic hot water. Federal, state, and local air pollution standards must be strictly complied with, and environmental impact statements are required when using these systems.

Waste Heat Boilers. These are used in conjunction with high-temperature heat recovery such as that generated by engine exhaust. Such systems can also be used in conjunction with the exhaust given off by gas turbines, which can then be used to drive refrigeration equipment or electric generators.

Solar Energy

Although solar energy is free, the cost of the systems required to harness that energy has kept them more in the concept stage than in the application stage. But with the dramatic rise in the cost of energy, the cost of solar energy systems has become more realistic. An additional incentive for investigating and using these systems is that the energy source—the sun—is both infinite and pollution-free. Solar energy systems are currently used primarily for hot water heating and, to a lesser extent, for space heating.

Hot Water Heating. The typical solar hot water heating system, shown in figure 4.22, consists of flat plate collectors, storage tank, controls, and circulating pump. The solar collector is the heart of the system; it uses direct and diffused energy from the sun to heat the water. It is usually necessary to have one square foot of collector for each gallon of hot water used by the system. The thermal performance of the system usually depends on five factors:

1. Climatological and meteorological conditions.
2. Collector size, design, and construction.
3. Orientation of collector and tilt angle with the horizontal.
4. Size of storage tank.
5. Temperature of domestic hot water.

Space Heating and Cooling. Using solar energy for space heating and cooling involves significant capital investment. The present state of solar technology makes solar space cooling practically out of the question due to prohibitive cost. Advances have been made in the utilization of solar energy for space heating, but the state of the art limits practical applications to supplementary heating provided in conjunction with existing conventional heating systems.

The four key components of a solar heating system are collectors, piping and/or ducts, storage capacity, and controls. The number of collectors required varies with the climate where the system is being used. The collector area usually ranges from 20% to 50% of the total building floor area in order to provide 20% to 70% of the annual heating requirements. Piping or ducts are required to connect the solar collectors with a storage tank and the installed HVAC system; proper insulation is re-

quired to keep thermal losses to a minimum. The storage system is usually a metal or concrete tank; in general, two to five gallons of storage are required for each square foot of collector area. Controls for the solar system operate circulating pumps, which divert warm water from one storage tank to another, or directly to the load. In addition to pumps, there must be fans in an air system to blow air through the collectors or storage tank in response to climactic conditions and building load.

The existing heating system of a building determines the type and size of solar system required. In most cases, however, significant modifications are required to enable a satisfactory interface.

lengthy payback. It is important to consider not only the cost of the equipment needed, but also the cost of associated changes likely as a result of the modification, including new duct work, new partitions, and controls. These costs and paybacks must be weighed against other types of expenditures and returns on invested capital.

Conclusion

This chapter highlights a variety of energy-conserving measures that have proved cost-effective at colleges and universities. A more complete list may be found in appendix B. The modifications selected by a campus will depend on the variables in a specific situation,

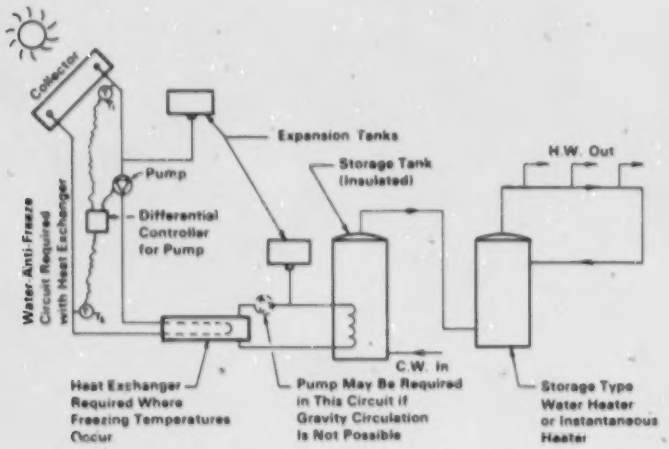

Collector
Expansion Tanks
H.W. Out
Storage Tank (Insulated)
Pump
Differential Controller for Pump
Water Anti-Freeze Circuit Required with Heat Exchanger
C.W. In
Heat Exchanger Required Where Freezing Temperatures Occur
Pump May Be Required in This Circuit if Gravity Circulation Is Not Possible
Storage Type Water Heater or Instantaneous Heater

Figure 4.22. Solar Water Heating System

Although utilization of solar energy has received much publicity, the feasibility of its use on a campus must be studied carefully. Unless funds can be obtained for participation in a demonstration project, or unless climatic factors are extremely favorable, solar energy systems convert options should probably be placed low on a list of *present* priorities.

As mentioned earlier, systems convert options must be analyzed prior to implementation, since many convert modifications involve technologies that are in the developmental stage. Continual improvements are made in such technologies, and thus the potential obsolescence of currently available systems must be evaluated. Also, systems convert modifications usually involve a substantial cost and

i.e., amount of capital available, engineering capability of the staff, complexity of building systems, and geographic location. However, no matter what energy-conserving steps are chosen, the following must be kept in mind:

1. *Careful planning* at all stages is required; a well-conceived and coordinated program will yield desired results.
2. *Accurate data* on energy cost and consumption, cost of modifications, and return on investment must be developed so that priorities can be established and performance monitored.
3. An *evolutionary approach* to energy conservation must be the basis of a program so that obvious waste is quickly

and cheaply eliminated prior to moving into modifications requiring capital and longer payback periods, and so that familiarity with all modification options can be increased.

4. *Constant review* and updating of program plans and progress are critical for maintaining momentum and for identifying further conservation economies.

Effective energy management is a critical goal if colleges and universities are to continue to provide the services for which they have been established. Each institution must insure that every possible dollar or bit of energy that can be saved *is* saved; this will not be easy and will sometimes be frustrating. However, a carefully planned, evolutionary approach to energy management will be a major step toward insuring the economic and academic future of institutions of higher education.

Purchased Utilities

In most cases, the analysis of purchased utilities can result in increased efficiency of use and in lower unit costs. Such utilities include electricity, coal, fuel oil, gas, steam, and water. Since electricity usually represents the largest portion of the overall utility bill, most of this chapter is devoted to the electrical component of the total utility bill.

Rate Structures

Most electric utilities have several rate structures; some have ten or more, such as residential, residential all-electric, general, heating, temporary, supplementary, and outdoor lighting. In addition, these are subject to one or more riders, such as power factor, auxiliary and emergency service, primary service, high-voltage service, and space heating service.

Utility companies may be contacted for information on their different rates, services, schedules, and riders, and most companies have customer service representatives who will review operations to suggest ways of economizing. However, the institution must initiate action. At one major university, physical plant managers meet with their electric utility representatives once a month for lunch. Almost every meeting results in the institution's staff returning with information that is helpful in terms of energy cost savings and in planning future developments.

When the institution has determined what utility services are available, a survey of electricity use should be performed for each separate service location. At a minimum, the following should be determined:

1. Rate schedule and riders used.
2. Maximum demand and period of occurrence.
3. Power factor.
4. Monthly and annual energy consumption.
5. Average cost per kWh.
6. Service voltage level and secondary use level.
7. Transformer and equipment ownership.

It is also advisable to talk with other customers of the utility who are in a similar position in order to determine the rate schedules being used, the use characteristics, and the amount being paid.

A critical review of at least one current bill for each service should be undertaken, and the following questions should be asked:

1. Is the institution receiving its discounts?
2. Is the bill computed properly?
3. Why is the institution on this rate?
4. Why does the institution not qualify for a better rate?
5. Should metering be consolidated?

A satisfactory answer to each question should be obtained. Local utility representatives may be contacted for assistance in answering these questions and requested to review each service. They should be asked if other rates apply or could be made to apply, and the advantages and disadvantages of each rate should be determined. It should not be assumed that the utility's calculations, or even rates shown, are correct. Mistakes often are made, and thus it is necessary to check figures.

As an example of what such a survey and review can yield, one university found that changes in electrical service over a five-year period resulted in three out of seventeen services either not being billed properly or not being billed at the most advantageous rate. The review also demonstrated that the total

campus service was being metered improperly. The immediate billing correction alone resulted in enough short-term savings to pay the cost of the study.

In another case, a facility was being billed on a standard commercial schedule. A review of usage patterns in light of the utility's rate schedule indicated that the facility could switch to an industrial rate, since air conditioning load was more than 50% of total kWh demand. A rate switch was made and savings of $39,960 a year were realized.

Accurate analysis requires expertise. In some cases this may be available at the institution, but in other cases it may be necessary to obtain assistance by working with other utility customers and with utility representatives. Consultants may also be used, but in any event, it is necessary to obtain the best possible guidance. Utilities are not required to provide the best rate; they provide information on the alternatives if asked, but it is up to the institution to make a decision.

Federal Power Commission

The Federal Power Commission (FPC), was established by Congress in 1920 to administer the Federal Water Power Act. Through subsequent acts and laws, its duties were expanded to include regulation of interstate *wholesale* rates of electricity and natural gas. The FPC thus has no jurisdiction over what an electric or gas utility may charge (retail). In the event that gas or electricity is purchased under a special agreement, it should be recognized that wholesale purchases usually are made from an *intra*state supplier—not an *inter*state supplier—so the FPC is not involved.[1]

Control over the *retail* rates of public utilities is left to the various state public service commissions. The logic behind the establishment of such commissions is based on the fact that a utility is a legally authorized monopoly. As such, it must be subject to some degree of public control. The degree of control is usually very limited, however, and primarily covers revenue. In almost all cases, public service commissions do not initiate action. Rather, their usual involvement is based on the following: the utility, using its experience and projections, decides that more revenue is needed in order to keep operating properly and to meet needs for expanded facilities; it then develops a case in favor of such revenues and asks the commission for rate changes, either in the form of new rate structures, or increased rates, or both.

The public service commission, upon receipt of this request, usually has an independent audit of the utility performed. In some cases other interest groups—such as consumer groups—will also have audits performed, or will scrutinize the figures of the commission and the utility. This audit is generally followed by public hearings, by changes in rate requests, and by a monitoring of utility revenues to insure the rate change eventually granted—assuming one is granted—is justified. It should be emphasized that most public service commissions are interested in the service component of the utility. The commission wants to insure that utility companies remain economically healthy and that the pursuit of economic health does not result in undue hardship to the consumer.

Public service commissions, as a result of energy consciousness, are taking more consumer-oriented initiatives. Nonetheless, commissions like the FPC do not generally become involved with the technical needs of the individual consumer. Accordingly, an institution should be completely familiar with its rights under law; a copy of the state's public service commission statutes should be obtained and read, and questions about the statutes should be addressed directly to the commission. Once familiar with rights under the statutes, an institution should not hesitate to exercise them. For example, if a utility is requesting a rate change and the change would affect the institution, the following questions should be asked:

1. What would the rate increase mean to this institution?
2. How do the institution's projections and those of others compare to the utility's?
3. How do data on past usage patterns compare?

It is extremely important that the institution be heard on these issues.

[1] For more information, refer to *The Federal Power Commission, An Informal Explanation of Its Organization and Work*.

Computing Utility Bills

One of the purposes of a utility survey is to analyze utility bills. The components of a typical electric utility bill are:

1. Energy charges.
2. Fuel adjustment charges.
3. Customer-related charges.
4. Demand charges.
5. Low power factor penalty charges.

All bills contain an energy cost component. Most electric utilities use a sliding block approach to billing, that is, so much per kWh for the first 1,000 kWh, and so much for each successive thousand. In most cases, the more kWh consumed, the less per kWh paid.

Many electric utilities have added an additional energy cost component to bills, called a *fuel adjustment*, which reflects the increased cost of fuel and which can amount to a substantial charge. Gas utilities have a similar component called a *purchased gas adjustment charge*, or PGA, which reflects adjustments to gas bills based on fluctuations in the wholesale cost of gas. Wholesale rates have been increasing, and as a result, the PGA has also been rising.

Some utilities also add *customer-related charges*. These are applied to cover part of the distribution investment, operating and maintenance costs, and the costs for accounting and collection incurred by the utility. If such costs are not billed separately, they may be included in the energy charge.

Demand charge is another important element of an electric utility bill, and is designed to make the customer pay a fair share of the utility's fixed investment in production, transmission, and distribution equipment required to meet the customer's maximum requirements. The utility bases its demand charge on the rate at which electricity is consumed. The more electricity used at any given time, the larger the utility's investment in generation, transmission, and distribution systems. For example, consider two users, A and B, as shown in figure 5.1.

Both users consume an equal amount of kWh each day. However, user A consumes electricity in a 24-hour day while user B consumes electricity in an eight-hour day. As a result, user B requires the utility to maintain generating and distribution capacity equal to three times the capacity required to supply user A. This means that user B requires three times the capital investment that was required to serve user A, and thus user B should be billed for the extra investment.

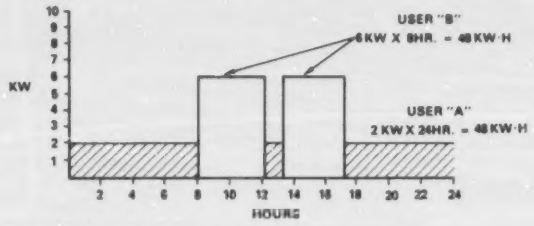


Figure 5.1. Comparison of Two Users

The consumer's actual demand is computed on the average amount of energy consumed in a predetermined demand measurement interval, usually 15 minutes (other intervals also are used by utilities, particularly 30 and 60 minutes). Regardless of the interval used, a utility takes the *highest* demand recorded during a given month and that demand becomes the *actual* demand for the month. The logic behind such a procedure is that, regardless of institutional average demand, the utility must continually have the capacity to meet this peak demand, which is expressed in terms of kW. Thus, if in one interval during the month a 200-kW demand is recorded, that demand becomes the actual charged demand, even if the next highest demand is only 100 kW.

Many utilities also employ a *ratchet clause*. Such a clause states that no matter what actual demand may be in any given month, the billed demand may be no less than a certain percentage of a demand recorded, typically during the summer months. In other words, if there is a 70% ratchet clause in effect, and a demand of 200 kW is recorded in July, at no other time during the year will a bill be received for demand less than 70% of 200 kW, or, in other words, never less than 140 kW. So, even though *actual* demand in December may peak at 90 kW, *billed* demand still will be 140 kW.

Another charge sometimes found, although generally not accounted for separately, is a penalty for low power factor. This is discussed in more detail below, but power factor essentially relates to how efficiently electricity is used. If the utility's goal for efficiency is met, there is no penalty incurred. If electricity is

not used efficiently, and a lower power factor results (usually below 90%), then a penalty may be assessed.

A typical utility rate schedule and calculation from the Potomac Electric Power Company (PEPCO), which services Washington, D.C., are shown on the following page.

The rate schedule is self-explanatory. Shown in the calculation are the following: the locale; the billing month and year; fuel cost, which relates to the fuel adjustment factor; an indication that this is a regular bill; that a total of 100,000 kWh were consumed; that the demand recorded was 300 kW; that there was no control demand, or billing demand, for a ratchet clause; and that sales tax is applicable.

The first item shown in the actual computation is the flat sum of $4.15, which is a customer charge. After this charge, the sliding block pricing comes into play: the first 6,000 kWh at 3.95¢, then 60,000 at 2.15¢, etc. The fuel adjustment is added on at a flat rate of .91233¢ per kWh. Demand, as can be seen, is also subject to the sliding block approach. PEPCO also adds the tax, resulting in an average of 4.06¢ per kWh.

Other bills may be far more complex than this one, especially in terms of power factor.

Power Factor

Many college and university administrators, to whom power factor was once only an academic problem, are now finding it a serious practical and economic problem due to growing nonlighting loads, more stringent ventilation requirements, and more critical voltage regulation requirements. The power factor relationship can be compared to a mug of beer, as shown in figure 5.2. Just as the mug contains both beer and foam, the power that must be supplied to any induction load such as an induction motor, transformer, fluorescent lamp, welder, or induction furnace is made up of real and reactive power. The real power, or the working power as it is sometimes called, may be compared to the beer. The unit of measurement of real power is the kilowatt (kW).

The reactive, or magnetizing, current is similar to the foam; this current is required to produce the flux necessary for operating induction equipment. Without magnetizing current, energy could not flow through the core of a transformer or across the gap of an induction motor. The unit used to measure reactive power is the kilovar, or kvar. As shown in figure 5.3, the vector sum (not the arithmetical sum) of the real power and the reactive power is the *apparent power*, which is measured in kilovolt-amperes, or kva. So, just as the mug has to hold both the foam and the beer, so must the wire and transformers carry the combined real and reactive power, which together are called apparent power, measured in kva. Power factor can be defined as real power (kW) and apparent power (kva).

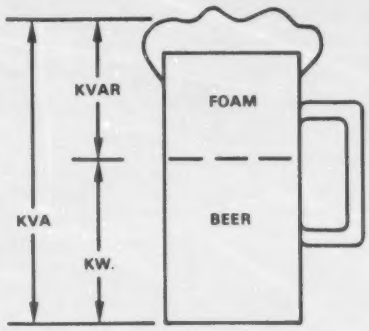


Figure 5.2. Power Factor Comparison

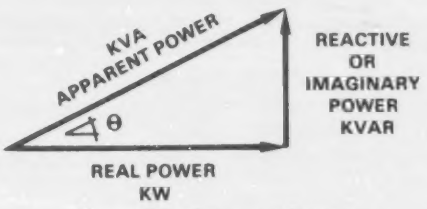


Figure 5.3. Apparent Power

Electric utilities must provide both real and reactive power for their customers. Reactive power does not register on a kilowatt-hour meter, but its production still requires the utility to put additional investment into capacitors and into generating, transmission, and distribution facilities. Many utilities make up for the expense of producing reactive power by including efficiency of reactive power use or power factor provisions in their rates. These provisions can take many forms; the local utility should be contacted to determine exactly which form is involved in a given case.

Many utilities are defining poor reactive power or low power factor as anything less than .9. Thus, if a building consumed 10 million kWh per year at 3.5¢ per kWh and had

Rate Schedule

Potomac Electric Power Company (PEPCO)
General Service Schedule "GS"

Monthly Rate	*Billing months of June–October (on peak)*	*Billing months of November–May (off peak)*
(A) Nondemand Billing Rate		
Customer Charge	$4.15 per month	$4.15 per month
Energy Charge	4.95¢ per kWh	3.95¢ per kWh
(B) Demand Billing Rate		
Energy Charge		
First 6,000 kWh at nondemand billing rates		
Next 200 hours' use of billing demand, but not more than 200,000 kWh	2.650¢ per kWh	2.150¢ per kWh
Next 200 hours' use	1.750¢ per kWh	1.300¢ per kWh
All additional kWh	1.480¢ per kWh	1.100¢ per kWh
Demand Charge		
First 25 kW of monthly billing demand	No charge	No charge
Next 75 kW of monthly billing demand	$4.75 per kW	$3.75 per kW
Next 4,900 kW of monthly billing demand	$4.50 per kW	$3.50 per kW
Excess of 5,000 kW	$4.25 per kW	$3.25 per kW

Minimum Charge—The charge for 50 kWh per kilowatt of billing demand at 7.50¢ per kWh, but not less than $6.00 per month.

Calculation

For: 1/ 1–21

Rate schedule—GSD (180)
Locale—D.C.
Billing month—February
Billing year—1976
Fuel Cost—0.91233¢/kWh
Regular bill—Yes (days—30)
Energy, kWh—100000.
Demand, kW—300.0 (300.0 kW)
Control, kW—0.0
Sales tax—Yes

Energy Charges:

	Energy Block (kWh)	*Rate*	*Charges*
	0.	$4.150 (customer charge)	$ 4.150
	6000.	3.950¢/kWh	237.000
	60000.	2.150¢/kWh	1290.000
	34000.	1.300¢/kWh	442.000
Total	100000.		1973.150
Fuel adjustment	100000.	0.91233¢/kWh	912.329
	Total energy charge		2885.48

Demand Charges:

	Demand Block (kW)	*Rate ($/kW)*	*Charges*
	25.0	0.00	0.000
	75.0	3.75	281.250
	200.0	3.50	700.000
Total	300.0		981.25
	Net electric bill		$3866.73
	Sales tax at 5.0%		193.34
	Total electric bill		$4060.07

(Average rate, cents/kWh—4.06)

a power factor of .87, its penalty would be calculated as follows:

$$\left(\frac{\text{kWh/yr.}}{\text{power factor}} - \frac{\text{kWh/yr.}}{.9}\right) \times \text{kWh rate}$$

$$\left(\frac{10{,}000{,}000}{.87} - \frac{10{,}000{,}000}{.9}\right) \times \$.035$$

$$= \$13{,}409.03$$

Practically speaking, a power factor improvement program, or at least a review of power factor economics, is appropriate for any institution that purchases electricity at primary level, that purchases on a large commercial or industrial power rate, or that maintains one or more of its own electric substations. More specifically, some power factor improvement will be worthwhile if institutional use of electricity is characterized by one of the following conditions:

1. Power demand is recorded on the bill in kva.
2. Electric rate has a kvar or power factor penalty clause.
3. The institution has problems with voltage regulation or chronic low voltage.
4. Load growth limits spare capacity and the institution needs more capacity.

Power factor improvement will save money in each of the cases listed above. It will reduce purchased power cost if electricity is bought on a kva demand rate; it will improve voltage regulation and ease any low-voltage problems, and will increase the power-carrying capability of transformers and feeders, thereby delaying the need for capital expenditures. These are the areas where power factor is significant, because power factor improvement releases locked-up capacity and increases the efficiency with which the copper and aluminum in the institution's electric system and in the utility system are used.

Where do the savings and cost reductions of power factor improvement originate? It is easy to appreciate the actual savings incurred if the efficiency or power-carrying capability of the distribution system is increased. Investment in distribution equipment will be smaller for a given power requirement. The savings associated with the avoidance or delay of a major investment in a larger substation are easily recognizable.

Similarly, many electric utilities grant reduced power bills for any power factor improvement made. A utility is willing to grant this award because power factor improvement at the extremities of the utility's primary distribution system is reflected in reduced investment for its entire power supply system distribution, transmission, and generating. The utility views these savings as an extension of the savings realized by an institution in terms of reduced voltage drop and released capacity.

Several devices designed and built for power factor improvement are available; the two most popular are synchronous motors and power factor correction capacitors.

Synchronous Motors

Synchronous motors are sometimes used in place of induction motors because of their ability to operate at unity or at a high leading power factor. These motors can do many of the jobs commonly done with induction motors, particularly when the load is steady and reasonably continuous.

Both unity power factor and .8 power factor synchronous motors can be used. The .8 power factor motor is more effective because it supplies leading kilovars at all loads up to its rating. The unity power factor motor supplies leading kilovars only when operating at reduced loads.

Most synchronous motors are available in sizes of 200 hp and up. The cost of a synchronous motor installation is high when compared with the cost of the equivalent induction motor with corrective capacitors. If synchronous motors are used, the added cost of controls and dc exciters must be considered. Obviously, an analysis to determine cost factors must be performed.

Power Factor Correction Capacitors

The most practical and economical method of power factor improvement involves the use of capacitors. The application lies in the fact that for a given cycle of power supply, during the first quarter of the cycle, a capacitor absorbs power while the inductor emits power. This sequence reverses during the next quarter cycle, reverses again in the next quarter cycle, and continues in this manner. Hence, a capacitor matched in capacity to the magnetic field of an inductive motor can supply or neutralize

the reactive power required by the motor through the phenomenon of continuous interchange of energy between an inductor and capacitor.

There are generally two methods of improving power factor with capacitors. The first is bank installations, in which a group of capacitors is connected at a central point such as the main switchgear or unit substation. In most cases, this method serves only to reduce the penalty charges of the utility company. However, it is slightly less expensive than the alternate method, which involves installation of individual capacitors directly at the source of poor power factor—at an induction motor, for example. Although this method is more expensive, it has all the benefits of the group installation plus the advantages of released system capacity, improved voltage regulation, and reduced power losses. This method is suggested by ASHRAE Standard 90-75 if power factor is less than 85%.

It is essential that capacitors be correctly sized. Proper size can be established by graphic determination, by checking various manufacturers' power factor correction tables, or by calculation. Some of the advantages offered by capacitors over other types of power factor correction devices are low cost, economic installation, no maintenance, movable capacity from one point to another in the distribution network, and correction capability, which can easily be increased. One university spent $60,000 on power factor improvement equipment, but the new equipment saved about $3,000 a month; the investment thus paid for itself in less than two years.

Demand Control

The basis for demand charges was discussed above. Demand is shown graphically in figure 5.4, which illustrates the peaks and valleys of demand. Obviously, the more consumption that can be tied into the periods when there are valleys, the more it will be possible to lower peaks and thus reduce demand.

The effectiveness with which energy is used is rated in terms of *load factor*, the ratio of energy use (kWh) to highest demand (kW) × time, usually measured as 720 hours (the number of hours in 30 days). For example, if consumption is 700,000 kWh in a 30-day period, and during that time a peak demand of 1,500 kW is established, a load factor of 64.8% would be established, derived as shown below:

$$\text{Load factor} = \frac{\text{energy use (kWh)}}{\text{highest demand (kW)} \times \text{time (hrs.)}}$$

$$\frac{700{,}000 \text{ kWh}}{1500 \text{ kW} \times 720 \text{ hrs.}} = 0.648 = 64.8\%$$

The lower the demand, the higher the load factor; the higher the load factor, the lower the relative cost for electric service.

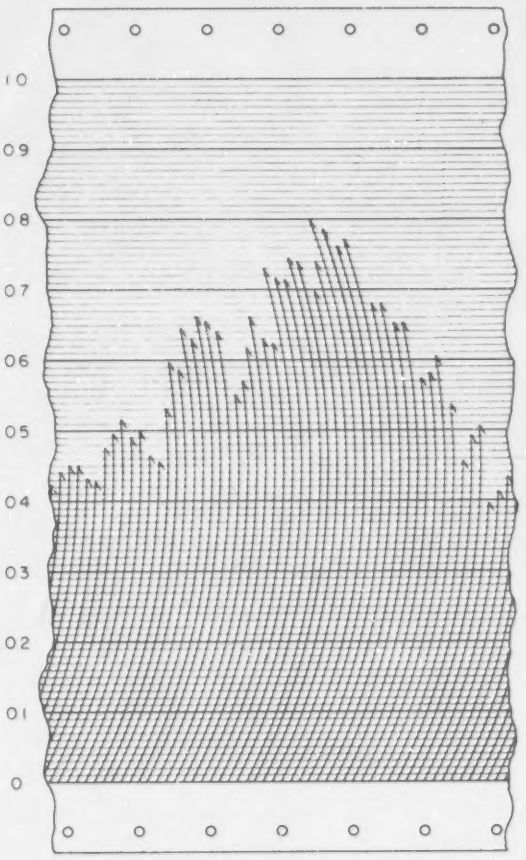


Figure 5.4. Typical Demand Chart

The techniques most frequently used to improve load factor are demand management and demand control. Demand control refers to the electromechanical procedure of load shedding; demand management encompasses demand control as well as other activties that can help reduce demand charges.

Analysis of Operating Procedures

An understanding of the potential for improving load factor can be gained by analyzing demand records to determine when demand peaks typically occur during operating hours. Demand peaks can be recognized easily, as shown in figure 5.5. An observation of operating procedures will identify which operations are responsible for peaks. Once these operations have been identified, it can be determined what must be done to sequence them in order to hold peaks down. For example, if two pieces of equipment are now started simultaneously, one should examine the possibility of sequencing start-up times so that surges do not occur at the same time. Could some operations be scheduled so that one begins after the other ends? The demand savings obtained can be significant, and such changes normally require little expense.

develop accurate data on how much power is being used by equipment at a particular time. Expansion or alteration planning at an institution, which may have impact on future demand requirements, should also be considered.

Identifying Primary and Secondary Loads

Each electrical load should be identified as either primary or secondary. A primary load cannot be interrupted; a secondary load can be interrupted, rescheduled, or deferred without causing problems in terms of comfort, process, or productivity. Typical secondary loads include the following:

1. Lighting.
2. Electric heating units.
3. Electric cooling units.
4. Chillers.
5. Air handling units.

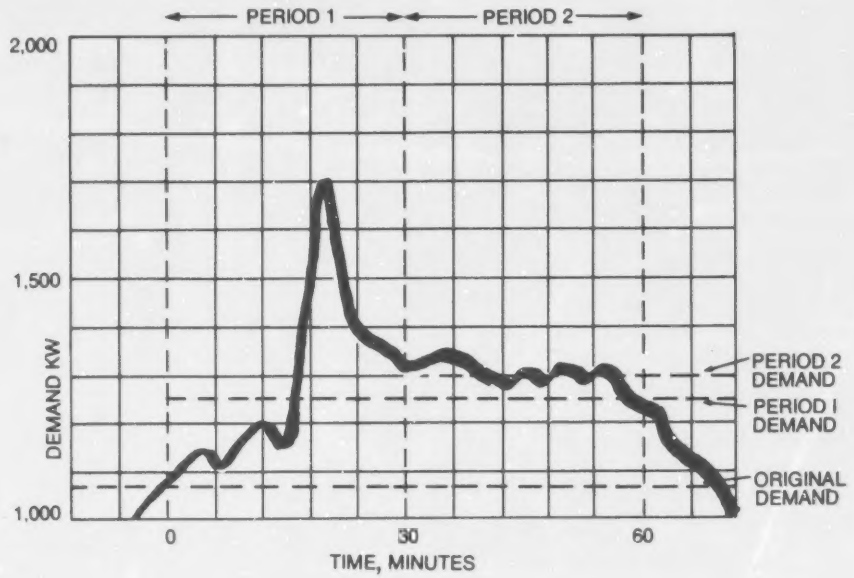


Figure 5.5. Typical Demand Graph

Developing Load Data

The specific research data needed to develop demand control system specifications may or may not be on hand; information on the rating of each electrical load is required. If comprehensive "as-built" drawings of electrical equipment are available, the task will be relatively simple. If not, the institution should consider undertaking a power survey using a recording wattmeter or other instruments to

6. Exhaust fans.
7. Water heaters.
8. Pumps.
9. Electric boilers.
10. Furnaces.
11. Ovens.
12. Incinerators.
13. Air compressors.
14. Loading dock de-icers.
15. Snow-melting systems.

Analysis of Secondary Loads

Once secondary or sheddable loads have been identified, determination of wattage ratings and establishment of shedding priorities are in order. The essential secondary loads should be given top priority, operating on a last-out, first-in basis; lower priority loads should operate on a first-out, last-in basis.

Before any decisions are made on which loads to shed, the potential impact of shedding on process, comfort, productivity, or environment should be analyzed. The effect that shedding may have on equipment should also be determined. Frequent operation of controls will usually shorten life expectancy and increase maintenance costs; such trade-offs must be considered and related to potential savings. When controllable loads and priorities have been identified, a determination should be made of how much demand reduction can be obtained, and the most cost-effective means for achieving this reduction.

Demand Control Systems

A demand control system is composed of three elements, as shown in figure 5.6.

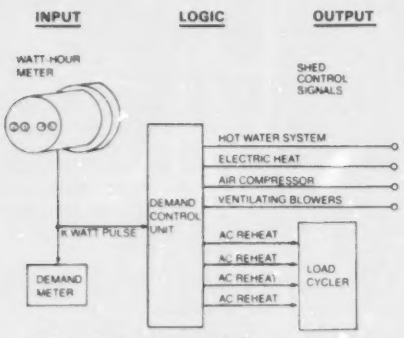


Figure 5.6. Demand Control System

Input. Input to most demand control systems is in the form of pulses from a utility company's kilowatt-hour meter utilizing a demand meter attachment. Each time a certain number of kilowatt hours accumulates, a pulse is generated. At the end of each accumulation interval the meter gives off an end-of-interval or EOI pulse. The pulse tells the control device that the interval is over and that a new interval has begun.

Logic. Logic refers to the operating method by which an automated demand control device performs the function of measuring the energy being consumed in a facility, and then limits demand by shedding certain secondary loads.

Demand control equipment ranges from relatively inexpensive units to highly sophisticated, large-scale computer systems. Simple systems generally operate by sounding an alarm whenever maximum demand is approached, thereby alerting personnel to proceed with manual shutdown. This type of system is useful for some installations, but such a system does not lend itself to highly effective demand control, since maximum demand can be easily exceeded if action is not taken immediately. An automated demand control system probably is the most effective type of installation in any serious effort to control demand.

The five logic systems generally used in such a system are: ideal rate, converging rate, instantaneous, continuous integral, or predictive.

A system of *ideal rate* demand control logic accumulates and compares the actual rate of energy used in any demand interval to a predetermined, ideal rate of use. As the actual rate of consumption approaches the ideal rate, secondary loads are shed. As the consumption rate declines, secondary loads are restored (see figure 5.7).

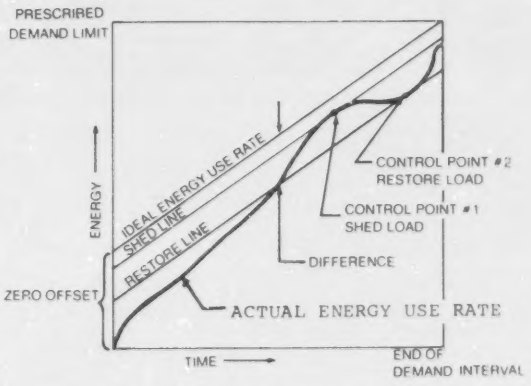


Figure 5.7. Ideal Rate Demand Control

A system of *converging rate* demand control logic is similar to that for ideal rate, except the ideal use curve and shed and restore lines converge at the end of each interval rather than running parallel. This type of system enables finer control over relatively small loads during the latter part of the demand interval,

when the accumulated registered demand may be very close to the maximum desired demand setpoint (see figure 5.8).

A system of *instantaneous* demand control logic compares actual rate of consumption at any time in the demand interval to maximum desired consumption at that time. On the assumption that maximum desired consumption is 1,000 kW for a demand interval, with straight-line accumulation or constant usage the accumulated demand should be no more than 250 kW at one-fourth of the interval and 500 kW at one-half of the interval. Loads are accordingly shed and restored following this criterion (see figure 5.9).

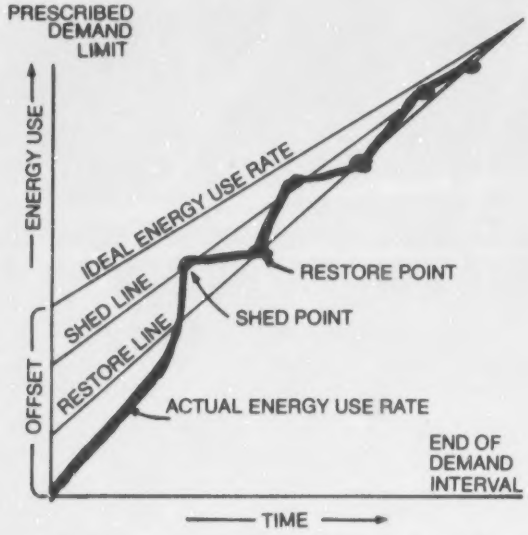


Figure 5.8. Converging Rate Demand Control

A system of *continuous integral* demand is similar to the system for instantaneous demand, since actual usage is continually monitored and compared to desired maximum rate. When the actual rate of use approaches the maximum desired rate, a secondary load is shed, but the actual shedding function is carried out by a satellite cycle timer which deactivates a secondary load for a fixed period of time. This deactivation results in demand interval overlap. For example, if a secondary load that stays deactivated for six minutes is shed at 14 minutes into a 15-minute demand interval, the load will stay shed for the first five minutes of the following interval. Continuous integral demand controllers compare the present interval usage to usage in previous intervals without restoring all loads at the end of each interval. This type of system reduces excessive short cycling of equipment and operating procedures.

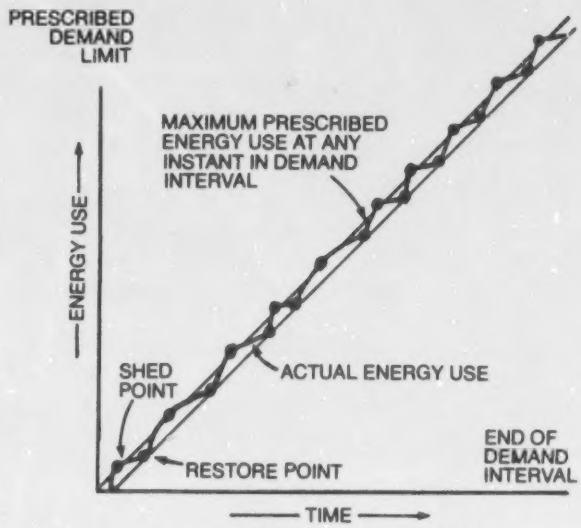


Figure 5.9. Instantaneous Demand Control

A system of *predictive* demand control logic measures total accumulated energy consumption from the beginning of a demand interval. A predicted or projected end-of-interval demand is developed, based on the rate of accumulated consumption measured at each point in the interval, and this rate is multiplied by the time remaining in the demand interval. If the predicted demand exceeds maximum desired demand, a secondary load is shed. If a subsequent measurement indicates a large enough margin, secondary loads are restored. Predictive method systems generally can accommodate a wide variety of load profiles, and in most cases are more expensive than other types of systems. They must also be compatible with utility demand-metering equipment for synchronous operation (see figure 5.10).

Output. The output function of automated demand control systems acts on decisions made by logic systems, thereby providing the actual control. Control is accomplished by activating relays, contactors, or motor starters that shed or restore loads so that peaks are leveled and valleys filled in, as shown in figure 5.11. The sequence in which secondary loads are shed can be altered. In some cases

a given load can be specified as the last shed and first restored, or in other cases the first shed and last restored. Demand control can result in substantial savings, especially when a ratchet clause is utilized. But, as in any energy conservation investment, cost effectiveness of the system is a major criterion in determining whether or not to obtain the system and what type of system to obtain.

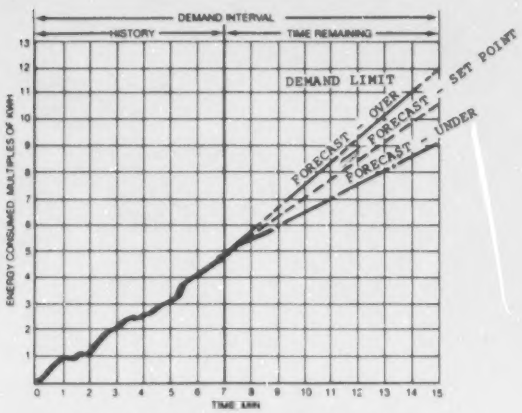


Figure 5.10. Predictive Demand Control

Utility Consultants

It may be necessary or desirable to call in a utility consultant to check data or to perform a comprehensive survey of electrical use. There are two basic kinds of fee structures commonly used by consultants: fixed fee and flat price plus percentage.

The consultant working on a fixed-fee basis will undertake the work for a predetermined fee so the cost of the work is known. The consultant working on a flat fee plus percentage will earn the most, based on the amount of savings obtained as a result of work performed. Typical contract elements for this type of arrangement are shown in appendix E. As can be seen, the contingency contract calls for a flat service fee plus additional fees for savings. In addition, this type of fee arrangement usually results in research into utility needs and billings, since any refunds will be shared by the consultant.

It is necessary to be cautious when retaining consultants. Friends, associates, and local organizations whose members may have used a consultant should be called. Background data on at least three firms should be obtained, and previous clients of the firm should be contacted to assess the quality of the firm's work. A meeting should be arranged with representatives of each of the three firms to learn more about their ability to assist in solving short-term problems as well as their ability to continue to provide service in the future.

Recordkeeping

Forms suggested for recording accurate data were presented in chapter 3. It is essential to keep all bills and related utility records properly filed so the records can be used for reference when the need arises. Although the bills received for other purchased utilities, such as water and sewage, are probably far less complicated than electrical billings, they should also be reviewed and all charges should be understood. Questions or more information regarding alternative rate structures should be addressed to a representative of the utility involved.

It is advisable to give one person the responsibility for collecting all relevant data for each month and for recording such data in the appropriate place on the form selected for use. This same person, depending on capability, could also be given responsibility for reviewing utility bills each month, making certain that proper rate schedules have been used and that computations are correct. Data should be analyzed to determine if consumption patterns are occurring as predicted, and if there are variances, to determine why and where they occurred. In short, the recording of data is one of the most important elements of any program designed to make efficient, cost-effective use of purchased utilities.

The Future

Four expected modifications of electric utility pricing are likely: rate inversion, flattening of the rate structure, time-of-day/seasonal pricing, and inclusion of environmental costs.

Rate Inversion

Rate inversion is the exact opposite method of pricing from that currently used by most utilities. Instead of having the unit cost of electricity decline as use increases, the cost would instead increase as a function of use. The impact of such an inversion is obvious to large users of electricity. While it might seem that

such a pricing structure could never be implemented, several states report that this type of rate is being actively considered.

Flattening of the Rate Structure

Through a process of rate structure flattening, customer and demand costs assigned to a particular rate would be recovered as a fixed charge or entrance fee to obtain electric service. Electricity used would be billed on a flat per-kilowatt-hour price.

Time-of-Day/Seasonal Pricing

Most electric utilities have several generating units. As the demand for electricity increases, the less efficient pieces of equipment are brought on line. When this occurs, utilities' costs per kilowatt-hour rise rapidly. A time-of-day pricing structure would simply follow the added costs of generation, maintaining that prices should rise whenever the system peak is approached.

Periods close to or equaling the system peak are usually easy to predict. They occur during the afternoon or early evening of hot and humid summer weekdays. If a rate surcharge could be instituted for those hours and that season, it would encourage less consumption during peak periods, when generation is relatively inefficient and generating costs are rela-

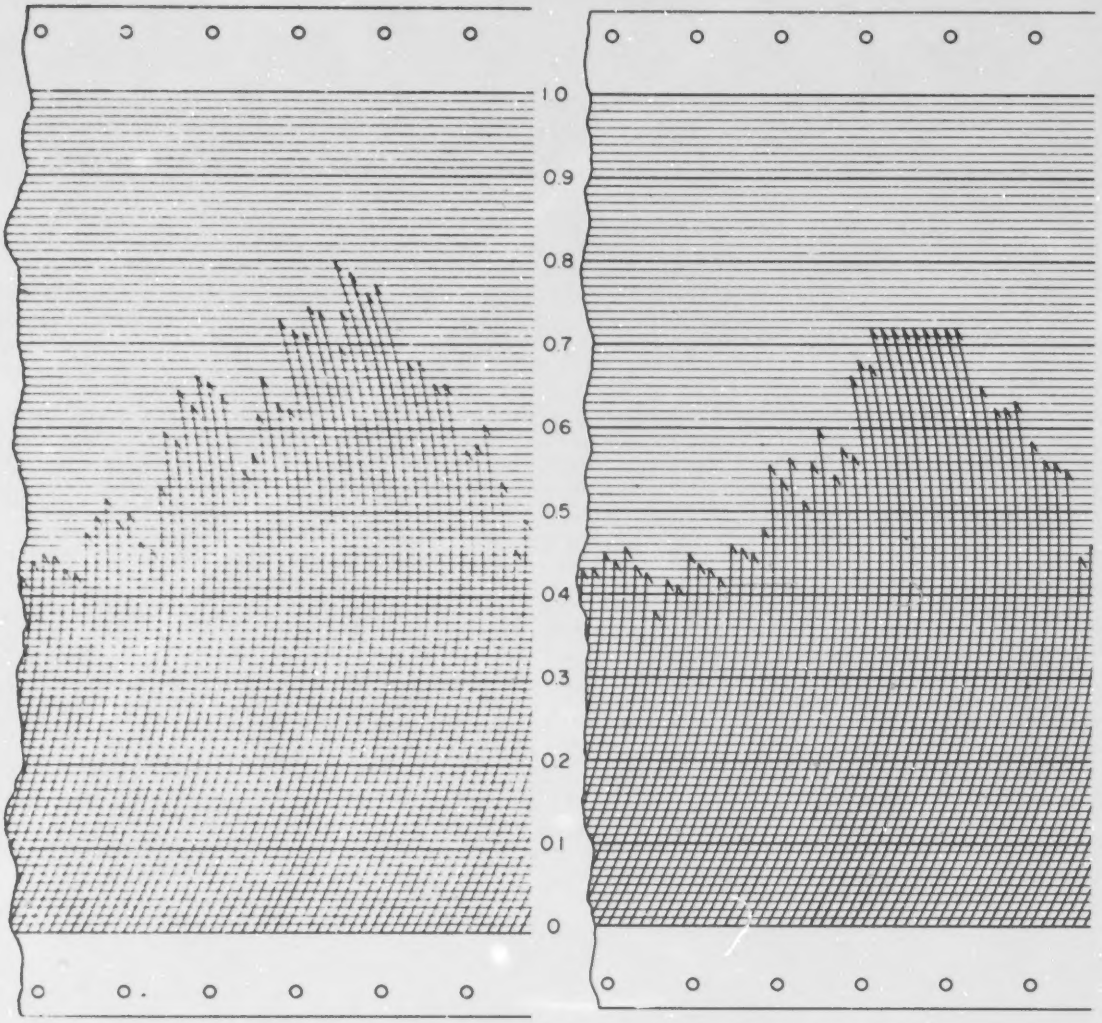


Figure 5.11. Demand Control (Without on Left, With on Right)

tively high. Time-of-day metering already exists, and major changes are likely in the future.

Inclusion of Environmental Costs

Another rate change likely to occur relates to the increased cost of power as a function of pollution control equipment. The magnitude of the rate increase will depend on the amount of pollution and on the types and severity of the pollution control regulations. Utility companies located in urban areas burning low-quality coal will be faced with the highest pollution control costs.

Impact on the Future

When new proposals are set forth, they should be addressed to determine how the institution will be affected, as well as the utility, the rest of the consuming public, and the nation itself.

6

Finance and Investment

In chapter 4 a variety of energy conservation measures and modifications were examined, and it was shown that opportunities exist for saving energy and dollars. The elimination of energy cost, or cost avoidance, is an annually recurring savings that allows an institution to use financial resources that otherwise would have been lost up the smokestack.

Specific energy consumption reduction measures and modifications for an institution depend on its size and complexity. Regardless of these factors, however, there will be a need to seek capital for certain modifications, and it will be necessary to make cost-effective use of this capital. Seeking funds and using them effectively will vary among institutions, but there are some common energy finance and investment techniques that can be of assistance to every institution.

As the range of conservation measures and their respective costs are examined, one should keep in mind that energy management is an evolutionary process. The focus should first be on those measures that appear feasible within the level of staff and in-house expertise available. The institution should not attempt to accomplish or implement all options immediately, but should move deliberately and carefully, choosing those measures that have the greatest impact and that can be effectively handled by the existing organization. This *step-by-step approach* will insure greater control over energy modifications and will assist in building the credibility needed to stimulate further funding of an energy management program.

Seeking Funds Outside the Institution

As a first step, potential sources of funds for an energy management program should be listed. Discretionary funds that may be available for general upkeep and maintenance, as well as sources of capital funds for major refit and systems convert undertakings, should be investigated. The type of information that will be helpful for each source of funds includes:

1. Name of source and person in charge.
2. Types of programs funded.
3. Types of funds disbursed (grants, loans, etc.).
4. Restrictions imposed.
5. Time requirements.
6. Format of request.
7. Data required to support request.

Questions on external sources can probably be answered by the agency or foundation involved. When possible, a few samples of previously approved proposals or budget requests should be obtained in order to have a better idea of what the agency considers a good request. Once a list of the sources of funds has been prepared, it should be reviewed. One should ask: Have all possible sources of funds been listed, including public agencies and private foundations? For example, the Energy Research and Development Administration (ERDA) is involved in cost-sharing contracts for demonstration of solar energy projects. Professional and technical journals may provide information on sources of funds.

In short, every possible source of present and future funds should be investigated, and comprehensive information should be kept on all sources with which there is regular communication. The institution's development (advancement) office is a valuable resource in the search for external sources of funds, both private and public, including alumni who may be interested in the program.

Seeking Funds Within the Institution

Three types of situations are covered below: (1) institutions both public and private with quasi-endowment funds and/or free capital, (2) private institutions with no quasi-endowment funds or free capital, and (3) public institutions with no quasi-endowment funds or free capital.

In the case of institutions with quasi-endowment funds and/or free capital, the energy investment decision is usually not complicated. If the proposed energy modification earns a greater rate of return than would be realized in the stock or bond markets, the measure is probably worth implementing. However, the problem in securing capital for such modifications in these institutions is complicated by the competition for free capital dollars.

For example, the type of case that could be made in such a competitive atmosphere is that investment in a new library requires initial cost plus continuing costs for maintenance and operations. To be able to afford those new costs, without additional revenue, the institution must reduce its annual operating costs. One of the best ways of reducing is investment of funds in energy conservation. Thus, when capital funds for the new library are available, the library's operating costs may be considered to be essentially "free" of an annual operating basis.

In the case of private institutions with no quasi-endowment funds or free capital, obtaining funds is more difficult. Although investment opportunities may be obvious, there may simply be no money available to invest. There are, however, several possible alternatives.

The first alternative is reduction of the operating budget and investment of "cut" dollars in energy improvements. Ideally, it could be stated that such a measure will result in a double savings, since the operating budget will have been cut and a return on energy investments will have been realized. The feasibility and effect of such a move must be carefully evaluated by an institution.

A second, somewhat unusual alternative is an energy conservation package for a prospective donor. Historically, it has been difficult to convince donors to give money for physical plant improvement, but such donations could be viewed in a different light. For example, a donor may give $1 million for a new building, and by doing so creates new annual operating costs for the institution; however, if the same donor could be convinced to give the $1 million for energy conservation modifications that could reduce annual costs by $500,000, the donor would have effectively given $10 million worth of endowment money, using a rate of return of 5%.

In the case of public institutions, the problems of acquiring funds are usually more complex than those faced by private institutions. Legislatures or other public bodies may be reluctant to increase budgets, even when a clear payback is evident; and if they are willing to do so, there may be strong pressure to spend these increases on new ventures rather than on long-term savings.

The economic arguments for energy investments by public institutions are the same as those for private institutions. Investment in energy conservation projects produces long-term savings for the institution and the taxpayer. However, the politics of public institutions are complex, and in some cases a rigid approach to budgeting may make it difficult to progress. It is necessary to carefully examine specific approval processes and to identify those persons needing the most persuasion, and then to determine how that "persuasion" can best be presented.

Resistance may come from the president of an institution because he or she is feeling pressure from a variety of departments for funds, and thus energy conservation expenditures may be viewed as of relatively low priority. A possible solution to this type of problem may be to plan an energy education program so that the academic community can understand the long-term benefits that such a program will bring.

If the legislature poses the problem, it may be necessary, with the president's permission, to work carefully with individual members to convince them that this is the type of program which they can bring before their constituents as a plan for saving tax dollars.

Economic Analysis Tools

Common tools used to perform financial analysis for energy investments are highlighted below. These tools are helpful for determining the range of energy investment alternatives available.

Life-Cycle Costing

The economic aspect of alternative energy modifications should be evaluated using life-cycle costing techniques, which are critical for determining the total cost of an energy modification over the useful life of the building or building system being modified. Total cost includes initial or capital cost plus estimated operating and maintenance costs, including such variables as interest rates, insurance, and the cost of fuel or energy.

The useful life component employed in life-cycle costing should be no greater than the remaining useful life of the building or system involved. To forecast costs over an extended period, the effect of inflation on labor, materials, and energy must be anticipated, and a reasonable rate of interest on borrowed funds must be assumed. If it can be shown on a purely financial basis that installation of equipment will result in savings, such options should be strongly considered. However, more than monetary factors have to be considered: it is also necessary to take into account the ease of maintenance, the possibility of fewer complaints, greater reliability, future availability of energy (at any price), and other considerations.

In utilizing life-cycle techniques to select between two systems, simple formulas can be used to determine if the additional initial costs of a more expensive system are merited in light of long-term cost factors.

Cost-Benefit Measures

The formulas used to analyze energy investments may be different at each institution. The two most common cost-benefit measures used to evaluate the relative merits of a given investment are *payback period* and *return on investment (ROI)*, and these are described in detail. In some cases, alternate methods may be preferred, such as *present value analysis*. The type of calculation most applicable at a particular institution, or most appropriate for a specific fund source, should be determined. Also, the choice of a method of financial analysis depends not only on institutional practice, but on the type of project.

$$\text{Payback period} = \frac{\text{Amount of investment}}{\text{Net annual savings} - \text{Annual depreciation}}$$

$$\text{ROI} = \frac{\text{Net annual savings} - \text{Annual depreciation}}{\text{Amount of investment}}$$

The initial cost, or amount of investment, is the full cost of installing the particular equipment or equipment modification. Net annual savings is the difference between the cost of the energy that will be saved by the improvement less all annual costs of owning and operating the equipment, such as interest and principal on borrowed funds, maintenance costs, insurance, and taxes if applicable. Annual depreciation can be calculated in several ways. Generally, a straight-line depreciation formula is used, wherein the cost of equipment is divided by its useful life; straight-line is recommended for this calculation.

Payback Period. This method of financial analysis is best suited for projects with high annual savings relative to capital cost. Most energy projects have a short payback period ranging from a few days to five years. For such short payback periods, inflation and the cost of money are not significant factors and thus are usually ignored.

Return on Investment. This method is most useful for comparing energy investments with alternative investments, and is also helpful when borrowed funds are involved, in order to insure that the annual savings will be sufficient to pay back the principal and interest as well as other annual costs. If the return on investment is significant, it is generally sufficient to undertake the ROI analysis for the first year, since increases in energy costs are likely to exceed those for maintenance and other annual costs. Thus, an improvement in the annual return on investment can be expected over time.

Present Value. This method of analysis is generally preferred when the annual savings are low compared to the capital investment involved. Present value is simply the price an institution should be willing to pay now to realize forecasted annual savings in the future. If the capital cost of a project is equal to or less than this price, the project is worth doing. The reliability of the present value method depends heavily on the reliability of forecasts for inflation of fuel costs and other items. Since it is so difficult to forecast future energy costs with certainty, this method must be used with

some caution when applied to energy management projects. Also, in present value analysis, it is not necessary to take depreciation into account, because the savings used in the calculation are limited to the useful life of the improvement. At the end of the useful life, a new present value determination can be made with respect to replacement.

Return on Investment: Example

The results of a sample return on investment calculation as they might appear on completion are shown below, as well as the way in which the return on investment data were derived.

Item	*Cost*
Installation of a heat exchanger in the central chilled-water plant to permit shutdown of chillers when the outdoor temperature is below 60°.	$60,000
Gross annual savings	$30,000
Annual maintenance cost	3,000
Net annual savings	$27,000
Depreciation or replacement allowance	7,000
Annual return on investment	33%

$$\text{ROI} = \frac{\text{Net annual savings} - \text{Annual depreciation}}{\text{Amount of investment}}$$

or

$$33\% = \frac{\$27{,}000 \text{ (step 4)} - \$7{,}000 \text{ (step 5)}}{\$60{,}000 \text{ (step 1)}}$$

where step 4 = step 2 − step 3

Step 1 is analysis of the *cost of the installation*. The cost is the sum of the following elements:

1. Feasibility study.
2. Engineering plans and specifications.
3. Equipment purchase.
4. Equipment installation.
5. Start-up costs.
6. Contingency costs.

Step 2 is determination of the *annual energy savings* expected from the project. If this is the first project of its kind at the institution, it will be necessary to rely on theoretical calculations made by staff members or a consulting engineer. For example, if the project is designed to reduce the amount of fresh air taken into a building, the quantity of air reduction can be calculated for the year, as well as the amount of energy it would have taken to heat the saved volume of air the required amount of degrees. The energy (Btu's) can then be converted into fuel consumed, taking into account the losses in the system. This quantity of fuel is then multiplied by the unit cost of the fuel to produce the annual energy savings for fuel. To this amount should be added the cost of electricity saved as a result of less demand on the fan used to move the air.

Such theoretical calculations are generally reliable, but they can be confirmed by subsequent metering of typical installations. Again, it is recommended that an evolutionary, step-by-step approach be followed so that theoretical estimates can be confirmed and so that overcommitment to projects that will not prove to be cost-effective can be avoided.

Step 3 is determination of the *annual costs of ownership and operation*. This step involves estimating or delineating the following elements:

1. Routine maintenance of equipment, including labor and parts.
2. Allowance for major repairs, if warranted.
3. Calibration and maintenance of controls.
4. Annual interest payments on borrowed money.
5. Annual principal payments on borrowed money.
6. Taxes and insurance.

Step 4 is calculation of the *net annual savings*. This is done by subtracting the annual maintenance and ownership costs from the annual energy savings (step 2 minus step 3).

Step 5 is determination of the *annual depreciation* or replacement costs. An institution may have its own formula for this calculation, but generally, straight-line depreciation can be used, i.e., dividing the equipment installation cost by the years of useful life.

Step 6 (optional) involves determination of the inflationary factors for maintenance, fuel costs, etc. Generally, this type of analysis is not necessary for fast-payback items.

The same type of procedure and analysis would be used for a payback calculation:

$$\frac{\$60{,}000 \text{ (step 1)}}{\$27{,}000 \text{ (step 4)} - \$7{,}000 \text{ (step 5)}} = 3 \text{ (years)}$$

To calculate energy savings to be obtained from any modification, savings should be counted only once. For example, if savings of fan horsepower as a result of a time-clock installation have been counted, those savings should not be counted again when it is proposed to connect the same fan to a computerized control system. In this instance, credit should be taken only for the additional savings that will result from a more flexible shutdown capacity.

It might help to calculate both return on investment and payback. In this way, the priority project would be the one that is best from both calculations.

Preparing the Proposal

The preparation and format of a proposal for funds are an important part of an energy management program, as the proposal must "sell" the plan. For purposes of this discussion it is assumed that data have been developed and that—either with internal staff or with a consulting engineer—an analysis has been made of the cost of each conservation option proposed and of the approximate energy savings to be realized.

Thorough identification of costs and savings based on valid data is critical for establishing credibility and for gaining the type of financial support an energy management program requires. Such information is especially important if a proposal must be presented before a board or some other type of funding authority. Persons responsible for allocating funds are not likely to be familiar with opportunities inherent in an effective energy management program, and thus they will need reassurance. They need to be clearly shown the type of cost, cost savings, and waste elimination that can result from a carefully planned energy investment.

With this need for clear identification in mind, and with the assumption that a thorough engineering analysis of conservation alternatives has been undertaken, a document must be developed that delineates the energy conservation modifications proposed, the capital costs of these modifications, the annual energy savings, and the return on investment and payback periods involved.

A sample summary page of a proposal prepared by one major university is shown as table 6.1.

The full text of another modification proposal is included in appendix C. It, too, has a page that emphasizes key items. Summary pages should be followed by thorough and accurate back-up information outlining each measure to be undertaken. Some of the back-up information often included for each option proposed is:

1. Identification of the problem.
2. Identification of the energy used.
3. Identification of the new equipment or system.
4. Specifications of several manufacturers.
5. Cost of equipment or system.
6. Expected life of equipment or system.
7. Amount of energy to be saved.
8. Current cost of energy.
9. Projected energy cost over the lifetime of equipment.

The proposal may also include requests for feasibility or engineering studies, which have no immediate return on investment, such as that associated with actual modifications. Nonetheless, these studies are required in order to understand the energy-saving potential of certain major refit or systems convert projects. It is suggested that these feasibility study requests be shown separately from other capital requests and that in describing a proposed feasibility study, identification of the purpose of the study, the approximate cost of the modification being considered, and the amount of energy involved be clearly stated.

The assignment of priorities may also be helpful. In table 6.2, projects are arranged on the basis of annual return on investment, the one with the highest ROI listed first. Similar tables may be subdivided into relatively high-cost and relatively low-cost items. Such a division is also useful in distinguishing among projects requiring capital funds and those that can be financed out of operating budgets.

No matter which format is chosen for the presentation of energy management modification proposals, clarity and ease of understanding are important. Concise descriptions of costs, savings, payback, and return on investment, accompanied by proper supporting data, are essential to demonstrate that the type of analy-

TABLE 6.1
Energy Consumption Reduction

A. Phased Capital Investments

	Cost ($000)	Estimated Annual Savings ($000)	Estimated Life (yrs)	Payback Period (yrs)	Estimated R.O.I. (%)
Quick Fix:					
Special Equipment Maintenance	76.5	15.0	5	5	19.6
Refit:					
1. Lighting: Incandescent and Fluorescent	79.0	75.9	10	1	96
2. Temperature Controls	65.3	33.9	15	1.9	52
3. Central Control Panel Additions	169.0	50.1	10	3.4	30
4. HVAC Systems Modifications	90.0	21.2	12	4.2	24
5. Miscellaneous Thermal Insulation (Storm Windows, Weatherstripping)	107.8	16.8	8	6.4	16
Total Refit	511.1	197.9	10	2.6	39
Systems Convert:					
1. Epidemiology and Public Health Building Modifications	200.0	100.0	12	2	50
2. Central Computer Control Systems	700.0	234.0	10	3	23
Total Systems Convert	900.0	334.0	10	2.7	37
B. Energy Technical Studies					
Five (5) Building Surveys	66.0	—	—	—	—
Total Investment Program	1,553.6	546.9	10+	2.84	35

SOURCE: Yale University, Phase II Energy Investment Program 1975/76.

TABLE 6.2
Energy Management Program

Location	Description	Estimated Cost	Estimated Annual Savings	Payback Period	Estimated Life of Installation	Estimated ROI	Date of Modification	Personnel Responsible
Gymnasium	Modify existing heating system and controls	$15,000	$9,000	1 yr., 8 mos.	12 yrs.	51.7%		
Dining Hall	Split Econostat zone and balance heating system	$ 4,300	$1,700	2 yrs., 6 mos.	12 yrs.	31.2%		
212 York St.	Modernize existing heating system and install automatic controls	$ 9,000	$1,700	5 yrs., 4 mos.	15 yrs.	12.2%		
Library	Service, repair or replace steam valves and traps	$12,000	$3,000	4 yrs.	5 yrs.	5.0%		

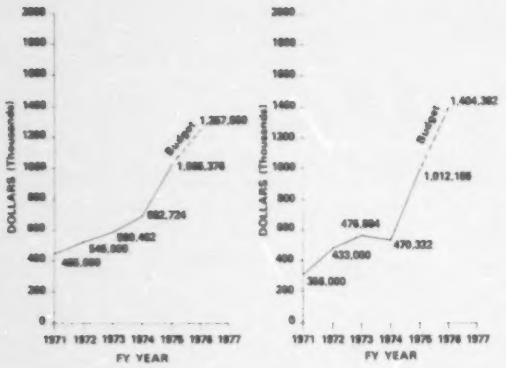
sis—both engineering and financial—that will lead to cost-effective use of funds has been completed.

Accompanying Data

After a proposal is prepared, it is often helpful to examine it in the context of the total institutional budget. This will not only provide reviewers of the proposal with an overview of the energy management program's effect on the institution, but will also help to sell ideas.

Historical data in chart form showing the trend of energy consumption over time, along with a projection of energy consumption, is helpful in grasping the magnitude of the problem. Such charts must take campus growth into account to accurately reflect energy growth. On these or on separate charts, it is useful to show growth in the unit costs of each fuel or utility. Figures 6.1 and 6.2 provide examples of the types of charts that may be helpful.

Discussion of cost avoidance is essential in

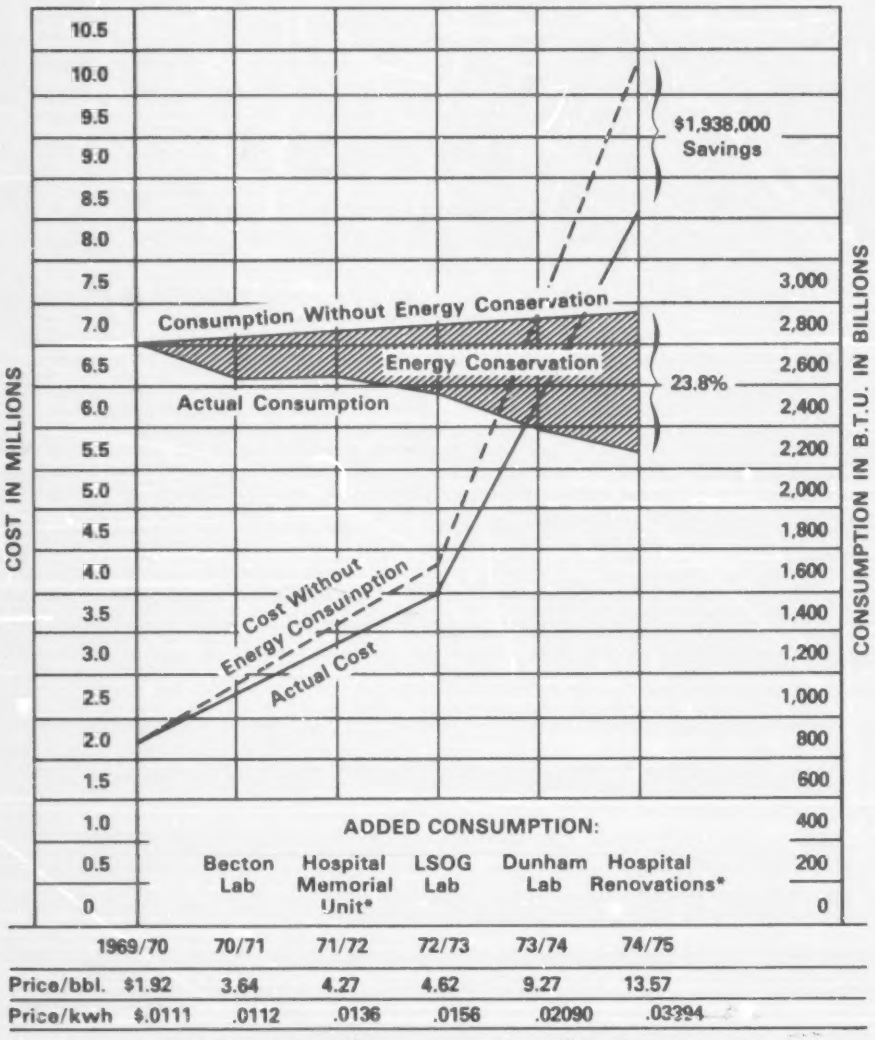


Figures 6.1 and 6.2. Electric Bills (left) and Fuel Bills (right)

any energy management proposal. It must be pointed out in the proposal that energy investment calculations show the annual consumption and cost savings if a project is implemented and that this savings, or cost avoidance, will be an annual return.

Figure 6.3 is a composite chart of consumption and price over time, showing energy costs with and without the implementation of energy-conserving modifications.

Energy costs shown as a percentage of the institution's budget and as a percentage of the physical plant budget are also helpful in making a case for conservation modifications.



*The Hospital purchases energy from Yale at cost.

Figure 6.3. Energy Conservation and Utility Costs

Energy Management and Organization Incentives

Modification of energized systems, such as boilers and chillers, and nonenergized systems, such as controls and building envelope, will result in energy savings, but the responsibility for developing, implementing, and sustaining an effective energy management program rests with a third component, which can be called the human system. No matter how much time, effort, and ingenuity is expended in quick fix, refit, and systems convert modifications, an energy management program cannot be very successful or effective without the understanding and support of the campus community.

The cost of energy is an important criterion in determining its priority within the institution. Persons who live and work on the campus have developed certain habits and expectations that may have been reasonable in the past but now are neither reasonable nor affordable. Thus, nearly every member of the human system referred to above will be called on to modify life styles in some manner and to develop a sense of energy awareness, which is necessary to the success of an energy management program.

The structure and impact of such a program will differ among institutions; each must tailor its program around its special needs and circumstances. Accordingly, certain parts of this chapter may have greater relevance for one college or university than for another. But the suggestions herein are based on the experiences of institutions where energy conservation programs have been successful.

Initial Organization and Action

Experience has shown that the effectiveness of an energy management program frequently depends on the ability of the physical plant director and chief business officer to work together on the development and implementation of an energy management plan. This collaboration helps to insure that the program is given proper technical direction and financial support and that an energy dialogue is developed between these two administrators.

After this cooperative atmosphere has been established and after energy cost and consumption data have been collected and analyzed, program priorities will begin to emerge. The highest priority should be given to those options presenting the greatest return in energy savings in the shortest amount of time using the least amount of capital—quick fix. As such modifications are implemented (and as records are kept of what quick fix changes are made, the amount of energy saved, and the return on investment), a broader based, longer-range plan should be formulated incorporating refit and, in some cases, systems convert options. Specific goals, the mechanisms and persons to be employed to achieve these goals, the amount of energy and dollars saved, and the payback period involved should be thoroughly identified in this broader plan.

Any effective energy management plan must also have a degree of flexibility built into it. That is, campus priorities, energy supply, and energy management technologies change rapidly. Accordingly, an ability to respond to these changes, while also moving forward in the effort to eliminate energy waste, mandates the development and administration of a carefully calculated plan that is at the same time broad enough to handle a variety of situations.

Setting Goals

The importance of setting clearly stated and reasonably attainable energy consumption re-

duction goals and working toward them cannot be overstated. Such goals can be set only after careful examination of cost and consumption data. An understanding of quick fix potential and a knowledge of funds available for energy management investment are also necessary before setting goals.

for one year at a time, future years should not be ignored. Because energy management is an evolutionary process, effective program development and implementation require time and evaluation. An energy management program cannot be developed overnight by the sudden application of sophisticated computer

TABLE 7.1
Energy Management Program

Location	Description	Estimated Cost	Estimated Annual Savings	Payback Period	Estimated Life of Installation	Estimated ROI	Date of Modification	Personnel Responsible
Gymnasium	Modify existing heating system and controls	$15,000	$9,000	1 year, 8 months	12 years	51.7%		
Dining hall	Split Econostat zone and balance heating system	4,300	1,700	2 years, 6 months	12 years	31.2%		
212 York Street	Modernize existing heating system and install automatic controls	9,000	1,700	5 years, 4 months	15 years	12.2%		
Library	Service, repair, or replace steam valves and traps	12,000	3,000	4 years	5 years	5%		

Realistic goals can be achieved by developing a step-by-step plan of action that not only addresses the modification of energized and nonenergized systems, but also takes into account the needs and idiosyncracies of the human system. One helpful method for clearly setting forth goals and plans of action to achieve these goals is the use of a clear and concise format for displaying energy management modifications and anticipated results. A format that could be used and that would be as intelligible to the chairman of the biology department as to the physical plant director is shown as table 7.1. This format clearly points out the facility or area to be modified, the type, extent, and cost of the modification, and the energy savings and payback period.

Other important data displayed are the life of the modification or installation, the return on investment, the date of the modification, and the person responsible for the modification. This type of action plan, set forth in a simple yet complete fashion, will be of benefit to everyone involved in the program and, in addition, will serve as an energy management program guide that will be of use in checking progress and monitoring performance.

Although detailed plans may be developed

systems or other capital-intensive substitutes for human effort.

Given the need for careful analysis and evaluation and the fact that a well-coordinated energy management program will yield significant short-term returns, an overall plan of energy management action should probably be developed spanning a relatively short period of time—approximately three years. A three-year plan is indicated in figure 7.1.

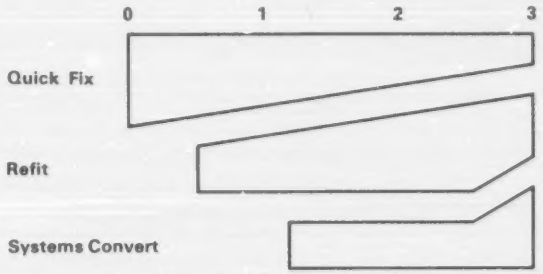


Figure 7.1. Three-Year Plan

During the first year, it is important to concentrate on quick fix measures as analysis of plans for refit and systems convert options is undertaken. The second year of a plan should probably include the implementation of specific refit measures along with further quick

fix measures, while the third year of the plan would, for certain institutions, focus on systems convert options.

Effective energy management is both an evolutionary and *simultaneous* process. That is, even as progress is made from one phase to the next, implementation of conservation measures in all three phases will be taking place. For example, as refitting of HVAC systems occurs, there may also be quick fixing of domestic hot water systems and removal of excess lamps; that is, one phase is never really finished. Each year, work in all three phases forms a part of the comprehensive program.

Gaining Understanding, Commitment, and Support

Since an effective energy management program affects the entire campus community and since it requires the allocation of capital resources, it cannot be successful without the understanding, commitment, and support of the senior administrators and the governing board. The pace and tone of a successful program must be set by those who control the organization.

This type of understanding and support will depend on sound energy management planning and accurate identification of energy-saving modifications having the potential for rapid return on investment. Accordingly, the physical plant director and the chief business officer should make certain that carefully constructed plans are developed and presented to the president.

The Campus Community

The campus community can be characterized as consisting of essentially three groups: faculty, students, and staff. At one time or another, members of each of these groups are affected by the energy management program, and thus it is advisable to keep each group fully informed of program goals and progress and, where appropriate to ask for advice. Insights, ideas, and cooperation can be gained from these groups if they are regarded as a resource and invited to participate. A campus energy committee is often a convenient and beneficial way to involve the community. By sharing and asking for ideas and plans and by making certain that these campus groups know why certain measures are being taken and the impact of such measures, understanding and support for energy management programs can be generated.

Faculty. Faculty members, especially department heads, are concerned about any program that affects their department, and thus it is important to gain their understanding, commitment, and support. Information on the energy management program should be available to them and briefings should be provided. In some cases faculty members, such as those in an engineering department, can be helpful. Expert, low-cost advice often can be obtained with the concurrent benefit of winning faculty support and understanding for the program.

Students. Obtaining the understanding and support of students is often difficult, since they are concerned with many issues and usually do not remain on campus for more than the time required to earn their degrees. However, some students may be interested in having a part in an energy management program; student agencies, such as the student council, can also be helpful. It would be worthwhile to seek out and employ such interest by using students as monitors to make certain that lights are out, by asking their assistance in reporting overheated or overcooled spaces, and by soliciting suggestions.

Operating and Maintenance Personnel. Operating and maintenance personnel as well as technical and clerical staff can also provide assistance in an energy management program in a somewhat similar fashion to that offered by students. Suggestions may be solicited, monitors assigned, and support urged so that this group of energy users is made to feel actively involved in the program.

Organizing the Review Process

Recommendations received from various groups must be given careful consideration, since they represent diverse interests, some of which may have been overlooked. Incorporation of worthwhile suggestions into the plan will make it that much more responsive to, and therefore supportable by, those it is intended to serve.

The goals of the energy conservation program must be kept in proper perspective with respect to the entire organization. An energy budget may range from 3% to 8% of the total budget, whereas personnel costs are a much

higher percentage. If energy conservation activities impair the productivity of people performing their assigned duties, they can quickly lose their cost effectiveness. A reasonable balance must be maintained.

Joint Committee

It may be advisable to ask a group of selected faculty, students, and staff members to serve on an ongoing campus energy management advisory committee, as shown in figure 7.2. Key faculty members, such as deans and department heads, as well as concerned students and staff, can be of major assistance in providing information on the effect and progress of a program. More importantly, a joint committee can help gain the type of commitment and support necessary to implement energy-conserving measures in all areas of the campus. It will be much easier for the head of the biology department to "advise" his or her constituents that the administrative offices in the biology building will not be heated on weekends than it would be for the physical plant office to make the same statement. Many institutions find it effective to have the president appoint such a committee. This not only invests the group with the type of credibility it needs, but also provides opportunity to further involve the president.

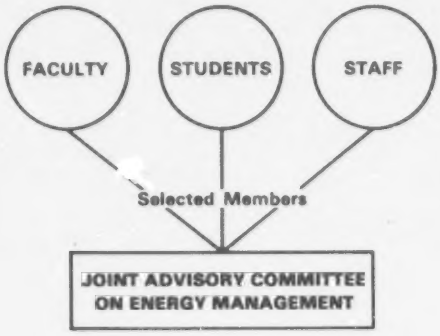


Figure 7.2. Joint Committee

The simple organization chart shown as figure 7.3 illustrates how the joint committee might fit into the overall energy management structure of an institution. In the example, the chief business officer and physical plant director prepare the original energy management plan for subsequent submission to the president in order to gain his understanding and support. Having gained this support, the chief business officer and physical plant director ask for comments and review by members of the faculty, staff, and student committee. Taking into consideration any worthwhile suggestions from these groups, the physical plant director and chief business officer revise the plan and—in this instance—ask for plan endorsement by the selected joint committee. The plan then is returned to the president for approval and announcement.

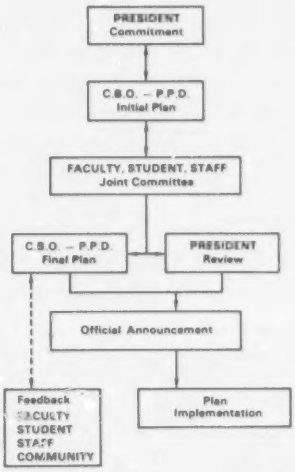


Figure 7.3. Organization Chart

Obviously, the model shown is the way in which the system would work in an ideal situation. However, while this approach is not the only way to implement an effective energy management program, it does point out certain critical components that will help to insure success:

1. Commitment and support from senior administrators.
2. Suggestions and approval from faculty, students, and staff.
3. Understanding from the campus community at large.

Organizational Structure

The organizational structure necessary to implement and maintain a successful energy management program should be carefully conceived. One such structure is shown in figure 7.4, which places the energy management department on the same level as all other key departments in physical plant. This arrange-

ment may or may not be appropriate for a particular institution. What is essential, however, is that some type of organizational structure be developed so that the energy management function is integrated into the existing structure in a way that will result in an effective program.

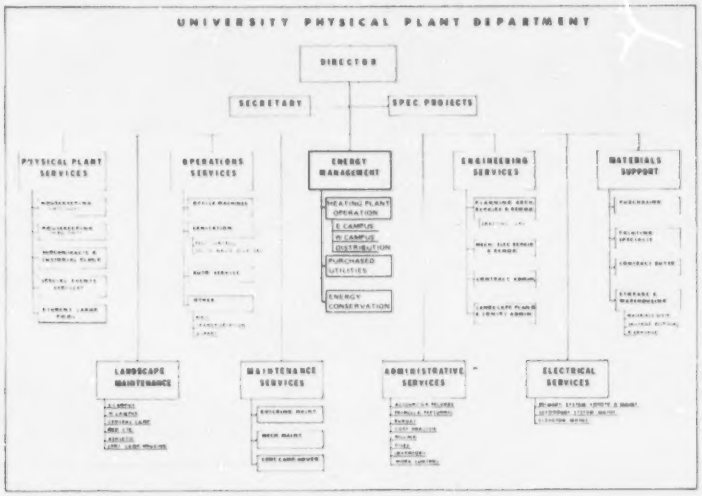


Figure 7.4. Organization Structure

Monitoring

A comprehensive energy management plan should also indicate the methods used and responsibility for monitoring the program, that is, for tracking progress and for insuring that reductions have been achieved and that systems are operating smoothly.

One of the key elements of an energy management program is the monitoring of data or the collection of energy cost and consumption information. Precise records must also be kept of program developments such as meetings held, projects initiated, and all other activities falling within the scope of the program. Similarly, the actual quick fix, refit, and systems convert modifications taking place in a program should also be monitored. Cost and performance must be controlled. Work must be inspected carefully, and occasional checks should be made of operating and maintenance personnel to insure that their jobs are being carried out as efficiently as possible, especially since an energy management program may require new routines and techniques.

Energy Monitors. Each group of building occupants can also be asked to appoint a person responsible for their facility in the context of the energy management program. The person appointed would help to insure that building occupants are aware of program objectives and that certain measures are carried out every day. Examples are making sure that lights are turned off during unoccupied hours and that thermostats are set back at night.

Energy Management and the Campus Community

The way in which an energy management program is presented to the campus community is important. Since, in many cases, schedules are to be altered, temperatures raised or lowered, lights removed, funds expended, and other energy- and cost-saving measures implemented that directly affect the community, care must be taken to convey the need for and results of such actions. Such an explanation or presentation will not only assist those responsible for managing the program in gaining the understanding of the community, but should also generate support and enthusiasm for the program.

Official Announcement

In order to provide the level of support necessary to generate campus awareness, many institutions have announced energy management program plans through the office of the

president. In many cases, such as the one cited in appendix D-1, the president has personally presented the plan.

A representative public announcement of the initiation of an energy management program would probably include such items as the reasons for the program, planned consumption reduction goals, and the types of modifications to be implemented, as well as the institution's position on such issues as temperatures, vacations, and scheduling. Any such announcement should also stress that saving energy is synonymous with saving money—money needed for people and programs. This point can be underscored by citing energy price increases over the last five years and the impact of such increases on the institution's budget. Ultimately, all of the reasons behind an official public announcement of an energy management program relate to the need to focus attention on the energy issue and to inform the community on what is to be done.

Departmental and Building Briefings

After the official public announcement of the program, consideration should be given to briefings in order to further explain program goals and modifications. Since class schedules may be affected, temperatures changed, lights removed, and other measures implemented, the more persons who can be reached on an individual or group basis, the more understanding and support for the program is likely to be generated.

Briefings need not be long or overly technical. Rather, they should be regarded as a chance to explain program goals and methods while also opening avenues of communication on energy between campus administrators and the rest of the community. A representative agenda of some of the topics that could be covered at such a meeting is shown below.

Agenda
Energy Conservation Meeting
Biology Department
Wednesday, February 26, 1976
11:00 a.m.

1. Current Status
2. Update on Energy Consumption
3. Problem Areas
4. Communication Activities
5. Energy Calendar

Each of these briefings should outline exactly what kind of changes will be made, how people will be affected, and the ways in which various groups can assist. The users of campus facilities should know what will be happening and should be asked for their support.

Ongoing Communications

The need for continuing communication with the campus community after the program has been launched is critical. Students, faculty, and staff must be kept aware of program progress, problem areas, measures to be implemented, and the amount of energy and money saved. Interest in and support for the program will quickly fade without this communication, and conservation progress can suffer as a result.

Newsletters and Brochures

Development and issuance of an energy newsletter and/or brochure explaining the energy management program will be of significant value. Existing resources such as campus newspapers, staff newsletters, and weekly calendars can also be used to convey program progress and conservation tips, as well as to give credit to those who have contributed significantly to the program.

Brochures need not be limited to one time only: they may be issued periodically, such as quarterly. They typically highlight energy conservation activities, progress, and plans for the near and long-term future. They also become a permanent and valuable record of the energy management program, a record useful not only for the campus community but also for the larger community—parents, alumni, and town residents.

Local Announcements

When possible, energy facts and figures for a specific facility, such as a gymnasium or energy-using entity such as a biology department, should be made available. Such information fosters interest as well as involvement on the part of those responsible for these facilities or departments. Some institutions have found that bulletin boards or large charts displaying progress in the reduction of energy consumption over time are useful. Strategically placed, these charts serve as ongoing reminders of the program, while also providing visible incentives for continued conservation of fuel and money. An example of the type of chart used by one

university for one of its facilities is shown in figure 7.5.

Major Policy Announcements

Energy conservation technology, as well as energy supply and demand, changes constantly. Foreign control of oil resources, development of alternate energy sources, and the needs of the campus itself mandate an energy management program that is constantly changing and reshaping as consumption reduction goals are pursued. Occasionally, situations may require either a relatively radical change in the energy management program or the institution of new conservation guidelines in order to maintain progress. Such major policy decisions or changes should be conveyed directly to the campus community by the appropriate administrator—in many cases, the president. For example, if the administration decides to prohibit the purchase of unit air conditioners, a policy announcement to this effect must be issued (see appendix D-2). Such a decision requires the endorsement and support of a senior administrator because of its mandatory nature and its potential controversy.

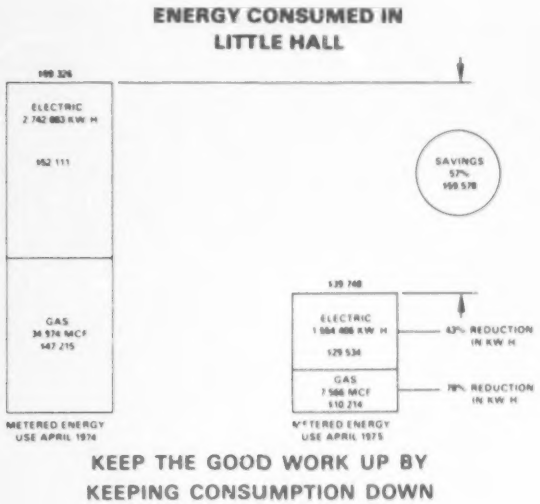


Figure 7.5. Example of Chart on Energy Consumption

Theme and Logo

Development of a theme and/or logo to characterize an energy management program will help in gaining program recognition and in sustaining enthusiasm for energy conservation efforts. A short phrase and/or an eye-catching logo will draw attention and provide identity to the energy management program. Phrases and logos can be used for a variety of purposes: promotional brochures, stationery, posters, bulletin boards, and even T-shirts. The more people who see the name and logo of the program, the more attention the program will draw. The more attention the program draws, the greater the likelihood that the campus community will become interested and involved.

Congratulatory Pieces

Persons who have made significant contributions to the program should be congratulated. A piece used by one university for this purpose is shown in appendix D-3. Giving praise when due is important in the effort to gain and maintain support.

Additional Ideas

There are a variety of additional promotion and recognition devices worth noting. In most cases, such supplementary aids are inexpensive, yet their use will prove beneficial in an energy management program.

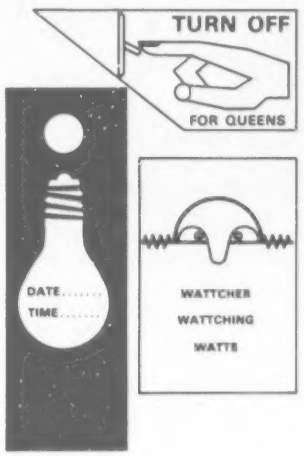


Figure 7.6. Point-of-Use Materials

Point-of-Use Materials

Point-of-use materials are labels and signs that can be affixed in appropriate places to remind people to take certain steps or to let them know that certain steps have been taken. (Examples are shown in figure 7.6.) Stick-on light switch labels can be used to remind

people to turn off lights when not in use; signs can be put on bathtubs and showers urging less use of hot water or to remind users that hot water temperatures have been reduced to conserve energy.

Conservation Telephone Line

Several institutions have established special telephone lines for reporting energy trouble spots or problems. These "hot lines" can be made even more effective by having numbers that correspond with words. For example, 468-5463 spells HOT LINE; 9-2783 spells WASTE; 36-3749 spells ENERGY; 266-7378 spells CONSERVE (without the E on the end); 288-2225 spells CUT BACK.

Advertising Program

Another option to consider is a public service advertising program—including billboards such as the one shown in figure 7.7—for use in campus media, including radio and TV stations, newspapers, magazines, faculty and alumni newsletters, bulletin boards, and classrooms. The nature of the ads will vary, but it would be worthwhile to concentrate some of the ads on the variety of ways the campus community can help reduce energy consumption, such as turning off lights, using the hot line to call in suggestions, keeping thermostats properly adjusted, and using hot water sparingly.

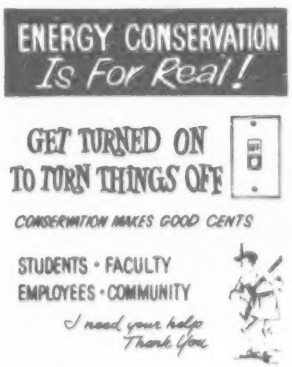


Figure 7.7. Advertising by Billboard

Conservation Contest

It may be possible to initiate conservation contests. For example, dormitories or residential units could be encouraged to see which unit can reduce energy consumption most dramatically over a specific time period.

Energy Conservation Short Course

It may also be possible to develop an energy conservation course for those interested in learning more about conservation potential and techniques. Thought should be given to integrating some of the work involved in an energy management program into the curriculum of other courses. For example, an engineering major could take a course in energy management and—through direct participation in activities such as a campus boiler efficiency analysis—earn credit.

Examples of the types of courses that could be offered are shown in appendix D-4.

Transportation

In conjunction with the program, an effort should be made to conserve automobile fuel, especially through use of bicycles and car pools. When encouragement is provided, it may also be necessary to provide service; for example, if bicycle use is advocated, bike trails and bike racks should be made available. If car pooling is promoted, preferential parking spaces for car pool users should be provided.

Summary

Many ideas have proved successful in organizing and managing energy programs at colleges and universities, but not all the measures mentioned here will be applicable to all institutions. There are, however, certain fundamental criteria for insuring the success of an energy program, and these are summarized below.

Teamwork is critical; there must be collaboration between the offices of the physical plant director and the chief business officer for a program to be effective, and it will be necessary to organize staff for maximum effectiveness.

Commitment from the president and *support* from the campus community will be instrumental in insuring progress.

Goals and objectives that are clearly stated will be necessary for keeping everyone aware of the design and direction of the program, and will allow evaluation of program progress and results.

Communication to and from faculty, students, and staff will be critical to provide proper service to the campus community, to understand its needs and problems, and, most importantly, to gain the support needed to make a program successful.

Evolutionary progress is the key to energy management success. To be effective, the program should move forward carefully and methodically so that energy savings can be attained and maintained.

In addition to these fundamental criteria, it may be helpful to utilize some of the suggestions given to develop, sustain, or improve an energy management program. Also, as the program progresses, *flexibility* will be required: a willingness to alter priorities and pursue new opportunities, to consider special requests, to realize that all goals may not be achievable or that new ones are in order. It will be necessary to change direction or to reassess efforts occasionally so that maximum energy savings can be achieved without compromising the academic mission.

Appendix A-1: Testing Boilers for Efficiency

Energy losses from a boiler are largely a function of the residual heat, both chemical and sensible, left in the stack gases as they issue to the chimney. Boiler efficiencies can be easily calculated from graphs if one knows (1) chemical composition of the flue gas, (2) temperature of the flue gas, and (3) type of fuel being burned.

In practice, the chemical composition is determined simply by a test for carbon dioxide (CO_2) content. The graphs in this appendix take into account both the amount of gas flowing per unit of fuel burned and the specific heat of that gas. The CO_2 reading establishes these parameters if the type of fuel is known. Furthermore, these graphs take into account the "latent heat loss" which is due to hydrogen in the fuels.

Carbon Dioxide Measurement

The amount of CO_2 in the flue gas indicates the efficiency of the combustion process, depending on the fuel. Since it is not practical to obtain perfect combustion in commercial equipment, maximum (or ultimate) CO_2 will not be reached; however, CO_2 should be maintained as close to maximum as possible without producing smoke.

Carbon dioxide can be measured by the conventional Orsat apparatus, but this is generally inconvenient to carry for field measurements. Small, convenient instruments for field use are typified by the Dwyer No. 1101 CO_2 Indicator or the Fyrite CO_2 Analyzer.

A low CO_2 reading is an indication that too much air is entering the boiler because either too much air is being admitted with the oil to the combustion chamber, or air is leaking into the ductwork at some point or points downstream of the combustion chamber.

The cause of a low CO_2 reading can be determined by taking a sample of gas from within the firebox (a stainless steel tube is needed to withstand the high temperature). High CO_2 in the firebox with low CO_2 at the stack means that there is a leak in the boiler casing or ductwork, which should be found and sealed. Low CO_2 in both firebox and stack means too much air is entering the firebox, in which case the following questions should be asked:

1. Can the air register be closed further without causing smoke?
2. Is the draft too high?
3. Are there leaks through the firebox bricks?
4. Is the oil not mixing properly with the air, due to either a bad match of oil spray pattern to air pattern (try nozzle of different angle) or wrong oil pressure or viscosity?

Stack Temperature

An important criterion in judging the efficiency of combustion is the temperature of the flue gases leaving the furnace or boiler. This measurement can be made with simple thermometers designed for this purpose.

The *net* stack temperature is the correct measurement. It is obtained by subtracting the ambient temperature from the flue gas temperature. For example, if the temperature in the stack reads 550°F (288°C) and the air temperature is 90°F (32°C), the net stack temperature is 460°F (238°C). The net stack temperature is required for the efficiency calculation; the actual stack temperature (in this case, 550°F) in-